INSIDE! Pull-out star chart

NEWS FROM TITAN:
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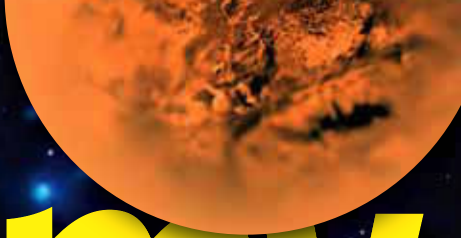

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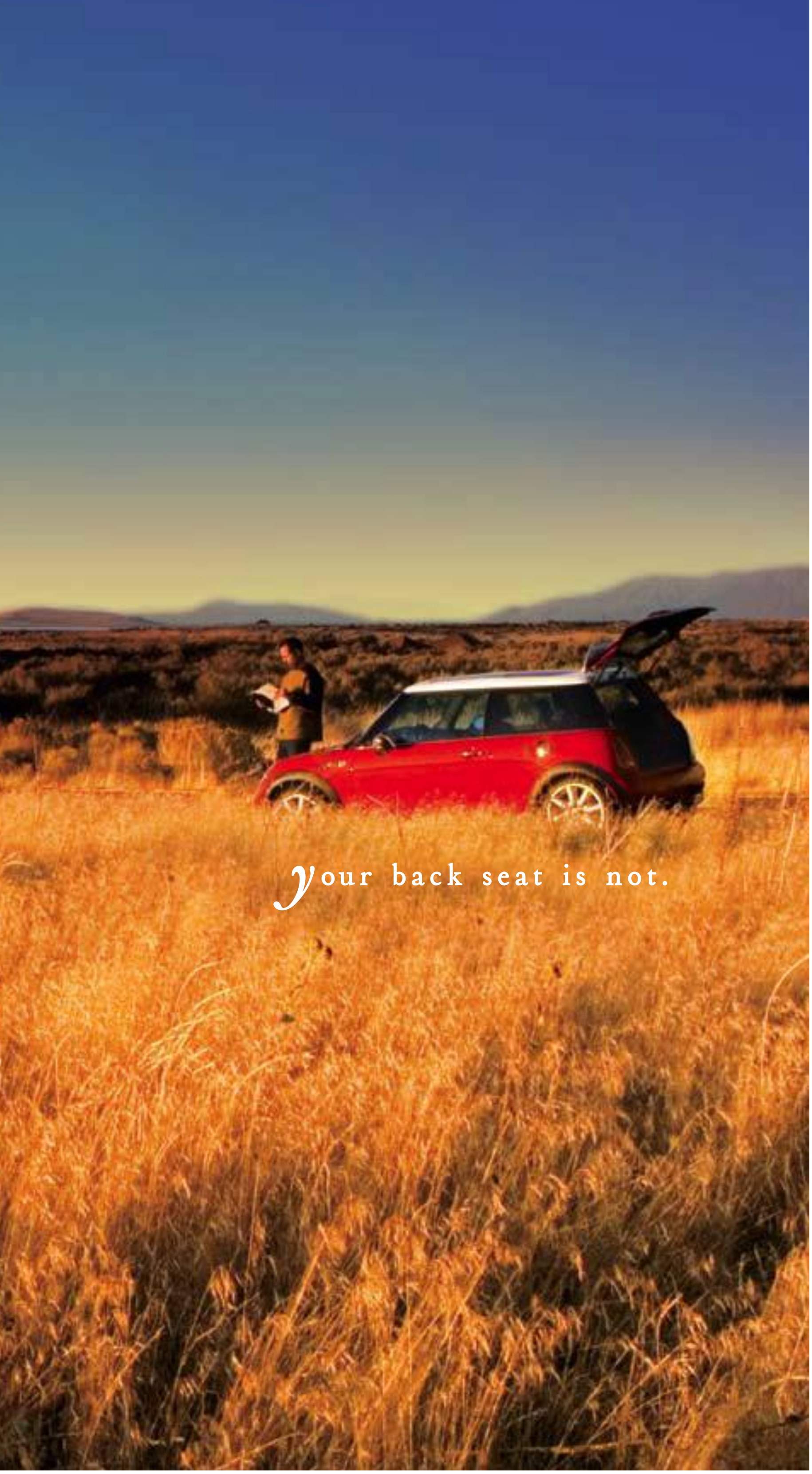

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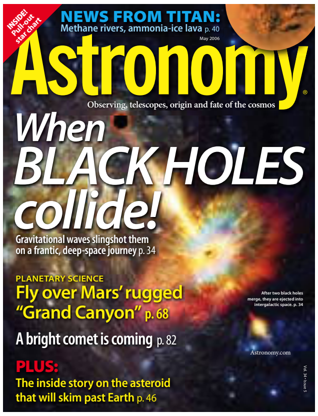
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ON THE COVER

Merging black holes emit gravitational radiation in the final moments of the collision. Just after they merge, the combined black hole may ride these waves out of its host galaxy. While this is an intriguing idea, scientists wonder how the process affected black-hole growth in the early universe.

Astronomy

VOL. 34, NO. 5

Observing, telescopes, origin and fate of the cosmos

may 2006

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BY DAVID J. EICHER

Of black holes and earthlike worlds

What happens when black holes collide?

It may be one of the most unusual questions astrophysicists ponder, and, now, scientists are focusing on an answer. In what may be one of the biggest "kicks" in the cosmos, black holes attracted to each other may spiral inward and coalesce into one — the product gets a jolt that sends it careening out of its host galaxy into intergalactic space, courtesy of gravitational waves. Recent calculations by Marc Favata of Cornell University, Scott Hughes of MIT, and Daniel Holz of Los Alamos National Laboratory kicked off a spate of papers and research about these black hole kicks.

In our cover story, "What happens when black holes collide?" (page 34), science journalist Steve Nadis presents these new findings and puts them in clear context.

While understanding that a population of rogue black holes may be out there is one thing, getting a grip on this phenomenon may help astronomers realize how supermassive black holes formed in the early universe. The Sloan Digital Sky Survey has uncovered such black holes in the early universe, but astronomers can't yet explain how these objects could have grown to a billion solar masses by the time the universe was a mere 900 million years old. Black hole kicks may clarify this process.

Mysteries of the early universe pre-dominate cosmologists' thoughts. Closer to home, planetary scientists are awash in the data returned by the Huygens probe that set down on Saturn's moon Titan in January 2005. As astronomers dig deeper into the information returned from Titan, they continue to marvel at the moon's similarities to Earth.

In "Saturn's Titan reveals earthlike surprises" (page 40), Bashar Rizk, head of the Huygens Descent Imager-Spectral Radiometer Team, guides you on a tour of the moon's methane rivers, ammonia-ice lava, and other features. It may sound strange, Rizk writes, "but no other place reflects what we see on our home planet as well as Titan — a horribly cold and inaccessible ball of ice and rock."

We're so used to living our lives on Earth's surface that we often forget to appreciate it as a planetary world of its own. That's exactly what astronomers searching for life in the universe need to do — study Earth first.

In "Searching for signs of life" (page 62), Carnegie Institution scientist Sara Seager explains how she and her colleagues study Earth in order to model alien worlds. Seager describes how engineers are designing the Terrestrial Planet Finder, an ambitious NASA mission that is slated to be launched in 2014, followed by a second, complementary craft in 2019.

These space telescopes will give astronomers their first legitimate chances at spotting earthlike planets orbiting other stars. Seager and her colleagues will look for biomarkers such as the molecules of life, the color signatures of life, and other features that may indicate distant worlds are inhabited by living beings.

If that discovery is made, it will be a startling moment for humanity.

Yours truly,

David J. Eicher
Editor

Astronomy
Volume 34, Number 5

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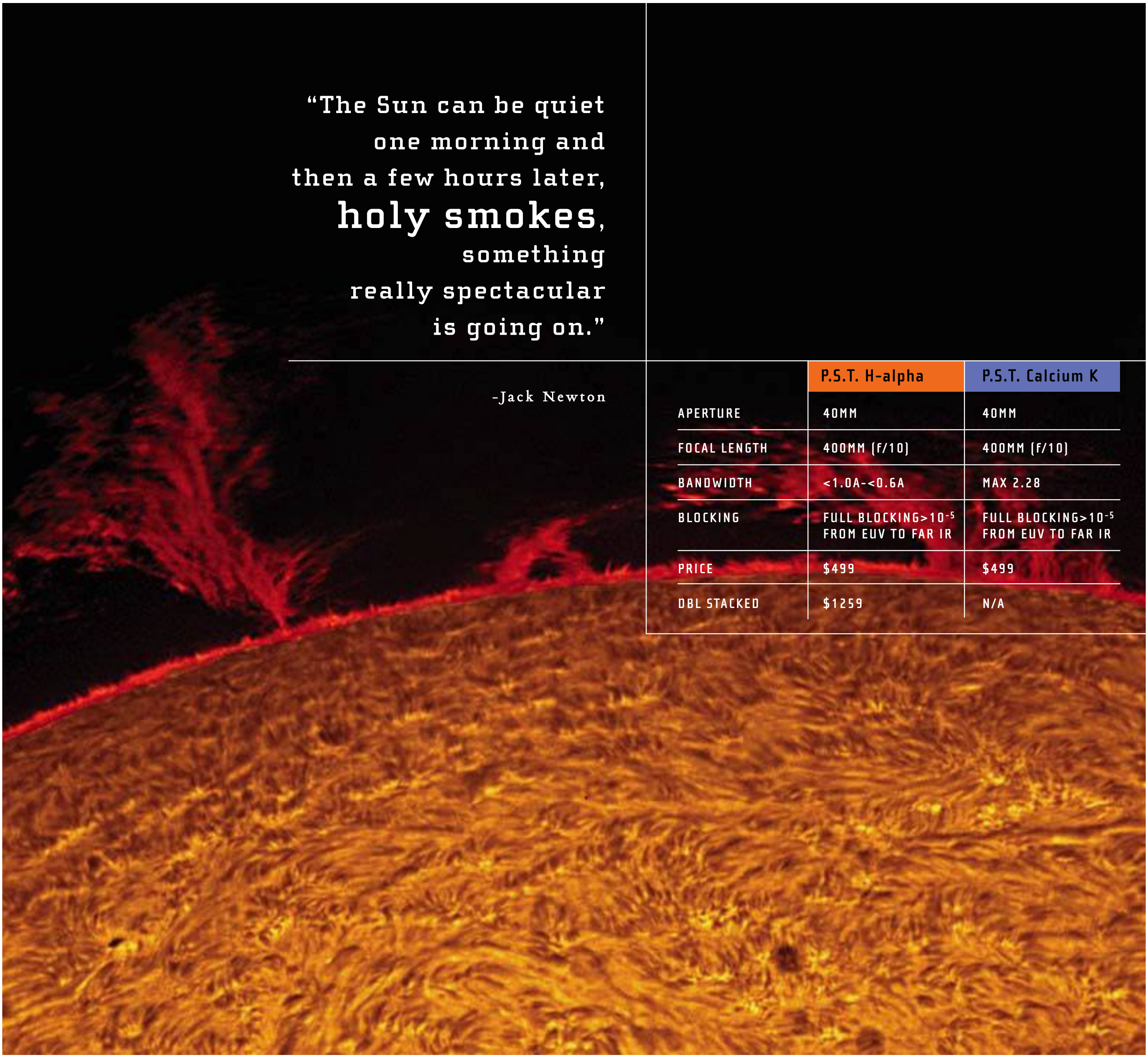

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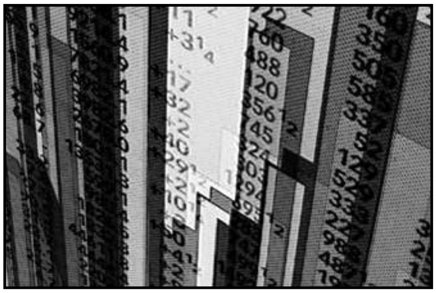

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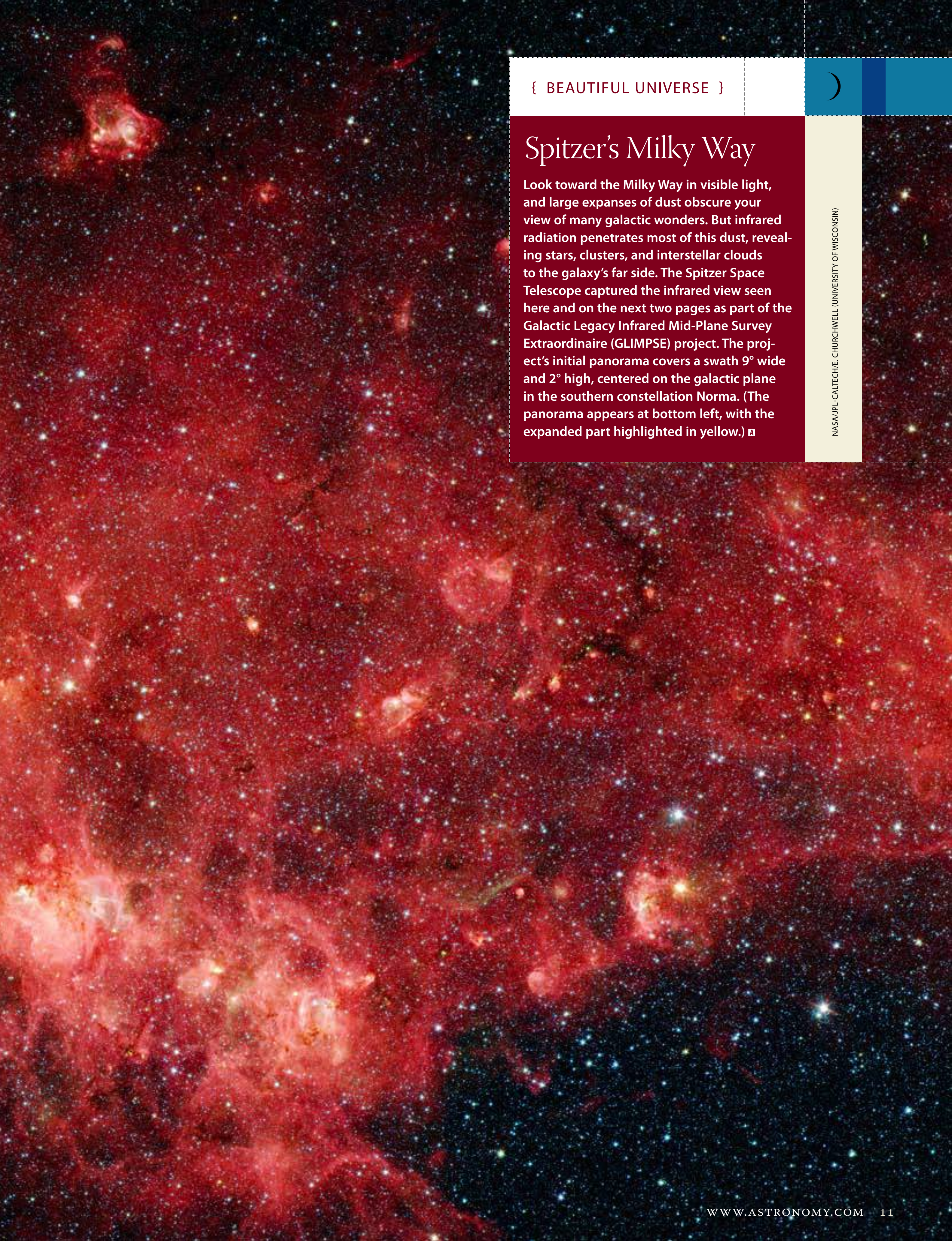
Spitzer's Milky Way

Look toward the Milky Way in visible light, and large expanses of dust obscure your view of many galactic wonders. But infrared radiation penetrates most of this dust, revealing stars, clusters, and interstellar clouds to the galaxy's far side. The Spitzer Space Telescope captured the infrared view seen here and on the next two pages as part of the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) project. The project's initial panorama covers a swath 9° wide and 2° high, centered on the galactic plane in the southern constellation Norma. (The panorama appears at bottom left, with the expanded part highlighted in yellow.)



NASA/JPL-CALTECH/E. CHURCHWELL (UNIVERSITY OF WISCONSIN)

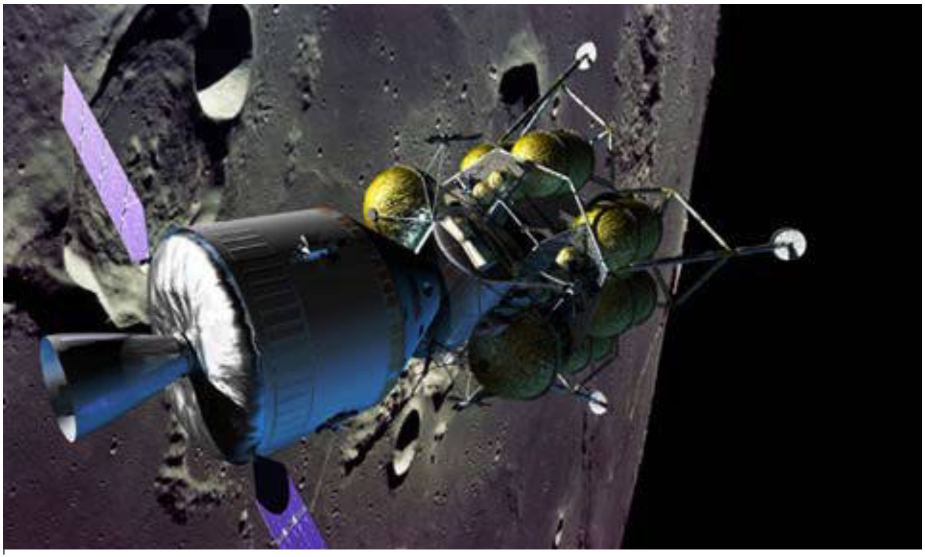
(continued from page 11)

Nowhere to go but up

Despite Francis Reddy's optimism in "NASA's next giant leap" (February 2006), I fear the U.S. manned space program is going nowhere. No human has walked on the Moon since 1972, when astronaut Eugene Cernan climbed back into his spacecraft and declared that humans, "God willing ... shall return." What happened to NASA's technological mastery of human space flight? The space shuttle is flawed, and the International Space Station was a mistake.

If President Bush were a true space enthusiast, he would follow through on his commitment to space exploration with priority funding. Human exploration of the Moon, Mars, and beyond would restore national pride and bring purpose to our space program.

If such visionaries as President John F. Kennedy, rocket-designer Wernher von Braun, and astronomer Carl Sagan were alive today, we probably would be walking on Mars by now. Let's keep the dream alive and make the unknown known! — **RICK SCHREINER,** SAN MARINO, CALIFORNIA



NASA/JOHN FRASSANITO & ASSOCIATES

NASA'S NEW SPACESHIP, the Crew Exploration Vehicle, will improve safety by combining the legacy of the Apollo program — a capsule with a launch escape system — with the most reliable elements of the space shuttle's launch system.

Give strings a chance

I was taken aback by Bob Berman's grousing about string theory in "Tangled up in strings" (January 2006). To suggest we abandon string theory makes about as much sense as describing that darling of the standard model — the point particle.

In view of the upcoming 2007 debut of the Large Hadron Collider, which could give indirect evidence of physics we can't probe directly, it seems premature for Mr. Berman to dismiss string theory.

The subject, in my mind, is far too elegant and powerful to be dismissed on any but the most rational grounds. If string theory doesn't exist in reality, what theory can challenge it? If one presents itself, I will give it the courtesy of objectivity and not rush to judgment. Nature has a way of making fools of us all. — **RALPH QUINN,** WOODLAND, CALIFORNIA

Mr. Quinn suggests we not rush to judgment about string theory. But, had there not been a shred of evidence to support relativity and quantum theories, nor any observational way of testing both, theoreticians would have moved on to other ideas.

Few physicists I speak with expect the Large Hadron Collider to provide acceptable proof of string theory. And, given string theory's ability to add or subtract dimensions or the properties therein — and, therefore, try to make anything fit any observation — it still won't satisfy the growing number of physicists who are unhappy with this whole thing. Neils Bohr said there's no point coming up with theories if you're not making observations — and that's the bottom line here.

This column presented and attributed the ideas of others. Considering that string theory already gets barrels of ink in the mass media, plus TV specials and best-selling books, I feel I can add more by presenting the other side rather than merely jumping on the string-waving bandwagon. In truth, I think that article was overdue. — **BOB BERMAN**

Correction

For the Apollo missions, NASA used the lunar-orbit-rendezvous technique to reach the Moon, not the direct-ascent method as stated in "NASA's next giant leap" (February 2006). — ***ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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20mm of eye-relief in all models. Adjustable eyeguard for use with or without eyeglasses. Perfect for Bino Vue and afocal imaging!

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Patented design using high index glasses, and tuned coatings make these sharper than other simple designs. You don't have to pay a premium for top-rated premium eyepieces.

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2—4 and 3—6mm give planetary eyepieces a new "twist." Tune power to the most sky conditions will allow. High contrast 5-element design with full field sharpness and constant 10mm eye-relief make Nagler Zooms far superior to other "planetary" eyepieces of equivalent focal lengths.

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"Optics don't get any better than this." — Backyard Astronomer's Guide

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Big brother of the NP101. "There isn't a better 5" refractor built." — C.J. (customer)

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We started **astronomics** over 26 years ago because we loved astronomy,

So good you'll swear it's an apo. But it's only $329!

Astro-Tech AT66 ED doublet optical tubes
your choice $329

The **Astronomy Technologies AT66** has an ED (Extra-low Dispersion glass) doublet optical system that the manufacturer says gives it apochromatic (color-free) images.

We won't go quite that far, but we will say that the **Astro-Tech AT66** fully-multicoated 66mm f/6 air-spaced ED doublet scopes are so sharp, contrasty, and low in spurious color that you'll swear they really *are* apos.

One customer said the only color he could see was on the *outside* of the tube. That's because you don't have to settle for an ordinary optical tube to get great optics. Express your individuality with a striking chrome, red, brass, blue, black, or white tube.

Each AT66 has dual speed focusing – standard speed and ultra-fine focusing at an 11:1 ratio. Each has a rotating Crayford-style focuser with a 1.25" compression ring eyepiece holder, a retractable lens shade; dust caps; and a fitted aluminum-clad carrying case.

Truly sensational optics at an affordable price; your choice of colors; and you get free shipping. What's not to like?

Compare prices. Dielectric diagonals starting at $69.95.

$139.95
$69.95
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You don't have to pay a fortune to get a genuine 99% reflectivity dielectric star diagonal. Top quality **Astronomy Technologies** dielectric diagonals start at only $69.95.

Astro-Tech diagonals come with your choice of either 96% reflectivity enhanced aluminum or durable 99% reflectivity *46-layer* dielectric first surface mirror coatings. All use 10mm thick 1/10th wave BK7 optical glass substrates. Each uses a non-marring brass compression ring to hold eyepieces in place. The 2" diagonals come with a 1.25" eyepiece adapter with a compression ring eyepiece holder at no extra charge. The 2" diagonals are available with your choice of a standard 2" nosepiece for use in a refractor or with a threaded ring that connects to a Schmidt-Cassegrain rear cell.

Here are the five premium quality **Astro-Tech** star diagonals that we keep in stock at very non-premium prices:

1.25" dielectric	**$69.95**
2" enhanced aluminum	**79.95**
2" dielectric	**89.95**
2" SCT enhanced aluminum	**139.95**
2" SCT dielectric	**149.95**

Celestron – ED refractor go-to made easy.

80mm Celestron C80 ED R-GT refractor
$1099

You won't spend all of your time hunting for sharp images of celestial wonders with a **Celestron Advanced Series** computerized ED doublet refractor.

A few touches on the NexStar computer hand control and your refractor speeds to any of 45,000 different stars, planets, and deep space objects. Then it will track it for as long as you want to observe through the sharp, contrasty, and virtually color-free ED glass optics.

Each has an adjustable height steel leg tripod, dual battery-operated motor drives, finderscope, eyepiece, and NexStar computer. Here are the ED versions:

80mm (3.1") **C80 ED R-GT**	**$1099.00**
102mm (4") **C100 ED R-GT**	**1574.00**

There's also a big 6" non-ED achromatic go-to scope available:

150mm (6") **C6 R-GT**	**$1069.00**

If you're a traditionalist and prefer a German equatorial mount without go-to, these Advanced Series scopes have adjustable height steel leg tripods, manual slow motion controls (motor drives are optional), finderscope, and eyepiece:

80mm (3.1") **C80 ED R**	**$799.00**
102mm (4") **C100 ED R**	**1299.00**
150mm (6") **C6 R**	**849.00**

> A belated thank you for the over-and-above price match. I appreciate it. I ordered my scope and case online last Friday afternoon about 2:15 . . . imagine my total surprise to get a shipping notice barely 2-1/2 hours later! And the shipment came yesterday (Monday)! I'll admit that one reason I chose Astronomics is because you're in Oklahoma and I'm in Texas (near Dallas) so I thought it would come quickly, but never did I expect THAT quickly. Now, to learn how to use the thing properly . . . LOL. Thanks again!
>
> **Customer Quote of the Month #170**

Meade ED triplet apo refractors start at $599. Wow!

$699
80mm ED APO package

Meade Series 5000 ED refractors use ED (Extra-low Dispersion) glass in their fully multicoated, air-spaced, triplet apochromatic optical systems. The ED glass provides extra high contrast, with no spurious color fringing around bright objects. It makes these refractors superb for wide field astrophotography, as well as exceptional for visual observing.

These are optical tubes only, with no mounts. They have adjustable lens cells, Crayford-style focuser, dust covers, L-bracket tripod mount, retractable lens shade, and a hard case.

There are also package versions available that add a $199 retail 2" dielectric star diagonal for only $100.

80mm ED, 3.1" f/6 triplet apo	**$599.00**
80mm ED, as above, w/2" dielectric diag	**699.00**
127mm ED, 5" f/7.5 triplet apo	**1799.00**
127mm ED, as above, w/2" dielectric diag	**1899.00**

We stock lots of TeleVue. Does your dealer?

NP-101 **$3685**
TV-60 **$825**

If it's TeleVue, we probably have it in stock. Others may say they carry TeleVue, *but we keep a six-figure TeleVue inventory in stock.*

Here are a few of the TeleVue telescopes we have on hand. These are optical tubes only, with dust covers and a carrying case.

TV-60, 2.4" f/6 apo	**$825.00**
TV-76, 3" f/6.3 apo	**1320.00**
TV-85, 3.35" f/7 apo	**1750.00**
TV-102, 4" f/8.6 apo	**2250.00**

The following scope packages (for use on your own mount) are also in stock. They come with star diagonal, Plössl eyepiece, tube ring, dust covers, and case.

TV-76, 3" f/6.3 apo	**$1725.00**
TV-85, 3.35" f/7 apo	**2150.00**
TV-102, 4" f/8.6 apo	**2685.00**
Renaissance, 4" f/8.6 brass	**3250.00**
NP-101, 4" f/5.4 Petzval apo	**3685.00**

As for TeleVue accessories, we have them all in stock. Need a Gibraltar, TelePod, or Panoramic altazimuth mount? A Sky Tour computer? Need a Nagler, Radian, Panoptic, or Plössl eyepiece? Need a Powermate image amplifier or a Barlow lens; an Everbrite 99% reflectivity star diagonal; a light pollution filter; one of the Dioptrx astigmatism-correcting lens? A BinoVue? No matter. If it's from TeleVue, chances are good we have it in stock. For example, here are a few of the eyepieces from TeleVue that we can ship today.

8, 11, or 15mm 1.25" Plössl	**$85.00**
32 or 40mm 1.25" Plössl	**118.00**
3, 4, 5, 6, 8, 10, 12, 14, or 18mm 1.25" Radian	**250.00**
2.5, 3.5, 5, 7, 9, 11, or 13mm 1.25" Nagler Type 6	**290.00**

Meade LX90 – LNT or GPS? It's your choice.

Meade 8" LX90-GPS
$1899
freight paid

Meade LX90 8" to 12" go-to SCTs are now available two ways – either with easy-to-use LNT (Level North Technology), or with automatic GPS. Most ship from our stock, so we save you shipping time over dealers who have them drop-shipped from Meade (and if you live in California, we save you the sales tax).

Here are the *freight-paid* prices on the LX90 scopes that we ship from our stock:

8" LX90-LNT	**$1799.00**
8" LX90-LNT, with UHTC optics	**1974.00**
10" LX90-LNT	**2299.00**
10" LX90-LNT, with UHTC optics	**2474.00**
12" LX90-LNT	**2999.00**
12" LX90-LNT, with UHTC optics	**3294.00**
8" LX90-GPS	**1899.00**
8" LX90-GPS, with UHTC optics	**2074.00**
10" LX90-GPS	**2499.00**
10" LX90-GPS, with UHTC optics	**2734.00**
12" LX90-GPS	**2999.00**
12" LX90-GPS, with UHTC optics	**3294.00**

Level North Technology makes it easy to line up your LX90 on the sky and start observing. Simply tell your LX90-LNT your location *or zip code.* It levels its optical tube by itself, aims it North, checks the time, then moves to its two alignment stars – *all automatically!*

With the LX90-GPS models, you don't even have to tell the scope your location. A built-in GPS receiver gets that information from Earth-orbiting satellites automatically. Once your scope moves to its alignment stars, check that its red dot finder is centered on those stars (you also get an 8 x 50mm finder), and start enjoying computerized go-to observing. An LX90 makes astronomy that easy!

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Celestron NexImage captures the solar system for $99.

The $99 **Celestron NexImage** CCD camera takes high power full color images of the Moon and planets with any telescope. It sends them to your computer to view live or print out later. The full color CCD imaging chip in the NexImage has a big 640 x 480 array of 5.4 micron pixels for sharp and clear high-resolution images.

For wider lunar panoramas, the optional $24.50 NexImage Reducer Lens will double the camera's field of view.

Celestron *SkyAlign* go-to scopes start at a low $279.

$379
80mm Celestron NexStar 80 SLT

You don't need to know the Pleiades from Polaris to find your way around the sky with a **Celestron SLT** go-to scope. With Celestron *SkyAlign* technology, just point your SLT at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet), and the SLT will find the planets and over 4,000 deep space objects for you *automatically.* A few anonymous points of light are all you need to find your way around the skies.

Celestron SLT no-guesswork go-to scopes are available in these sizes:

NexStar 60, 60mm refractor	**$279.00**
NexStar 80, 80mm refractor	**379.00**
NexStar 102, 102mm refractor	**479.00**
NexStar 114, 114mm reflector	**399.00**
NexStar 130, 130mm reflector	**439.00**

Each has *two* eyepieces, red dot finder, motor drives, stainless steel tripod, NexStar computer, software to control the scope from your computer, and more.

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Celestron's SkyScout *tells* you about the sky while it shows you the night's sights.

$399

The **Celestron SkyScout** is an award-winning handheld non-magnifying GPS-based personal planetarium that identifies or locates more than 6,000 celestial objects visible to the unaided eye, then tells you their facts and history. Use the SkyScout by itself to learn the legends, myths, and sights of the sky. Or mount it on your telescope to let it guide you from one celestial showpiece to another.

There's a scrolling 5-line display of text and graphics. Supplied earphones let you hear the commentary so you don't have to look away from the sky to read it. Optional speakers let others hear, too.

The SkyScout transforms the night sky into a planetarium for stargazers, families, and students. It makes learning the stories of the sky – *and finding your way around the sky* – easier than ever before.

Outer space is infinite. Your car's back seat is not.

Meade 10" f/5 standard LightBridge
$649

Meade LightBridge Dobsonians use a truss-tube design that lets even the big 12" models break down into a few small packages that easily fit into a compact car. One person can transport even the largest Meade LightBridge to a dark sky site and set it up on their own.

All Meade LightBridge Dobs have a 2" machined aluminum Crayford-style focuser with a 1.25" eyepiece adapter. A battery-operated fan on the metal primary mirror cell assures fast cooling of the diffraction-limited BK7 optical glass mirror. No tools are needed to assemble and break down the scope in the field.

Standard models have a 1.25" 26mm Super Plössl eyepiece, a red dot finder, and Teflon bearings. Deluxe models have a 2" 26mm 70° field QX eyepiece, an illuminated finder with four different reticle patterns, and roller bearings for smooth hitch-free motion at the touch of a finger.

The prices below include the shipping from the Meade factory.

8" f/6 standard LightBridge	**$469^{00}**
8" f/6 deluxe LightBridge	**569^{00}**
10" f/5 standard LightBridge	**649^{00}**
10" f/5 deluxe LightBridge	**749^{00}**
12" f/5 standard LightBridge	**949^{00}**
12" f/5 deluxe LightBridge	**1049^{00}**

A Meade Ritchey-Chrétien for only $2499? *Incroyable!*

Meade 8" f/10 LX200R Ritchey-Chrétien
$2499
freight paid

At least we think French optician Henri Chrétien would call it "incredible" if he were still alive and knew that the kind of telescope optics that he and George Ritchey designed – the kind used in the 300" Keck telescopes and the Hubble Space Telescope – were now available at prices virtually every backyard astronomer and astrophotographer can afford.

The new **Meade LX200R** telescopes combine 8" to 16" f/10 versions of the modified Ritchey-Chrétien optics used in Meade's famous RCX400 scopes with the superb mechanics of the best-selling Meade LX200GPS series. The result is true state-of-the-art telescopes at prices within reach and reason.

The 8" to14" LX200R scopes usually ship from our stock, saving you time over non-stocking dealers who must have Meade ship them to you (and if you live in California, we save you the sales tax).

Here are the *freight-paid* prices on the LX200R scopes that we ship from our stock:

8" **LX200R**	**$2499^{00}**
8" **LX200R,** with UHTC optics	**2674^{00}**
10" **LX200R**	**3399^{00}**
10" **LX200R,** with UHTC optics	**3634^{00}**
12" **LX200R**	**4399^{00}**
12" **LX200R,** with UHTC optics	**4694^{00}**
14" **LX200R**	**5999^{00}**
14" **LX200R,** with UHTC optics	**6349^{00}**

Because of their weight, these 16" LX200R scopes ship to you via truck from Meade.

16" **LX200R,** without mount, w/UHTC	**11,529^{00}**
16" **LX200R,** tripod, w/UHTC	**12,494^{00}**
16" **LX200R,** altaz pier, w/UHTC	**12,524^{00}**
16" **LX200R,** eq pier, w/UHTC	**12,779^{00}**

Serious solar observing for the price of an eyepiece!

CORONADO
P.S.T.
$499

For less than cost of some premium eyepieces, the sub-Ångstrom hydrogen alpha filter in the **Coronado PST** (Personal Solar Telescope) lets you see the ever-changing drama of solar flares and prominences growing and subsiding before your eyes. It doesn't just show you sunspots, as do ordinary solar filters.

The PST includes a dedicated 60mm refractor, built-in solar filter, a safe built-in Sun finder, and an eyepiece.

A 6 year-old can move your telescope.

$265

The **ScopeBuggy** scope transporter's 10" pneumatic tires, pivoting front wheel, and pull handle are so efficient that one customer's 6 year-old can move his 14" SCT all by herself.

A 45° multicoated image erector for only 59^{\underline{95}}$.

This 1.25" **Astro-Tech** image-erecting diagonal shows you the Moon and objects on the ground through your refractor or SCT the way they look to your bare eye, instead of reversed.

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21st century Celestron go-to . . . at a 1984 price.

$1399
Celestron 8" f/10 N8iSE

If you fondly remember the original orange-tube Celestron C8 – the scope that made amateur astronomy affordable – the **Celestron NexStar 8i Special Edition** will bring back the good old days . . . at a low price straight out of the 1980s!

The scope has a modern anodized version of Celestron's vintage orange and black paint, a convenient go-to computer with no-guesswork *SkyAlign* technology, and the bright images of Celestron's best Starbright XLT multicoatings.

The most amazing part? This 21st century telescope is available for less than the price of a C8 from 1984 that didn't even have a computer.

Amateur astronomy has changed a lot over the past 20 years. But a Celestron's value and performance are standards you've been able to rely on – *always!*

No-guesswork Celestron *GPS* Schmidt-Cassegrains.

Celestron 8" f/10 CPC800
$1899

It's easy to find your way around the sky with a **Celestron CPC**. Just point it at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet or the Moon), and the CPC will find over 45,000 deep space objects for you at the touch of a button.

You don't have to memorize a star chart to use a CPC. The scope's GPS system and a few anonymous lights in the sky are all you need.

Celestron CPC Schmidt-Cassegrains are fully equipped with all the features you need to start observing immediately.

8" **CPC800**, Starbright multicoatings	**$1899^{00}**
8" **CPC800X**, XLT multicoatings	**1999^{00}**
9¼" **CPC925**, Starbright multicoatings	**2349^{00}**
9¼" **CPC925X**, XLT multicoatings	**2499^{00}**
11" **CPC1100**, Starbright multicoatings	**2599^{00}**
11" **CPC1100X**, XLT multicoatings	**2799^{00}**

Celestron Dobs are nifty, inexpensive, *and in stock.*

8" f/6 StarHopper
$349

Celestron StarHopper Dobsonians use roller bearings for smooth hitch-free motion at the touch of a finger.

The 6" StarHopper comes with a 6 x 30mm finder, a 1.25" metal rack and pinion focuser, and a 25mm 1.25" Plössl eyepiece.

8", 10", and 12" StarHoppers have a big 9 x 50mm finder, 2" metal rack and pinion focuser (with a 1.25" eyepiece adapter), and a 32mm E-Lux 2" eyepiece. The 10" and 12" scopes have a battery-operated fan for cooling their primary mirrors. All scopes have fast cool-down metal tubes and BK7 optical glass mirrors, and all are in stock for immediate shipment.

Here are the prices for the fully-equipped Celestron StarHopper Dobsonians we stock.

6" f/8 StarHopper	**$249^{00}**	+ $59 freight
8" f/6 StarHopper	**339^{00}**	+ $69 freight
10" f/5 StarHopper	**499^{00}**	+ $79 freight
12" f/5 StarHopper	**849^{00}**	+ $129 freight

TMB-designed 60° field planetary eyepieces, $99.

Famed refractor designer Thomas M. Back created the **Burgess Optical** 4, 5, 6, and 9mm 1.25" planetary eyepieces to match the image quality of his $25,000 apo refractors. That they do it for only $99 each is amazing!

Do it to dew before dew does it to you.

Nasty old dew can do in your observing or astrophotography. Instead of mopping off your optics after dew has formed, it's easier to keep dew from appearing in the first place. We carry 67 different dew shields to slow the formation of dew, giving you more time to observe. We also carry 56 dew heater straps and controllers to prevent the formation of dew entirely, plus 16 heated dew shields.

We stock flexible, easy-to-store, roll-up plastic dew shields from **Astrozap** for most telescopes starting at $24.95; hard plastic ETX dew shields from **Meade** starting at $19.95; and a hard plastic CPC dew shield from **Celestron** at $42.95. We also carry **Astrozap** metal dew shields for most scopes, starting at $39.95, that have a baked-on finish to match the color of your scope's optical tube. Metal **Meade** dew shields for your LX90 or LX200 start at $140.

Heated flexible dew shields from **Astrozap** start at only $49.95.

We carry dew heater straps from **Kendrick**, **Astrozap**, and **Thousand Oaks** for all sizes and types of scopes at prices starting at only $25.

And dew heater controllers from **Thousand Oaks** and **Kendrick** start at $85.

The new Meade Deep Sky Imager *II*, $599.

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BY BOB BERMAN

Invasion of privacy

We spend our nights observing distant places. Most of these celestial bodies lie so far away and existed so long ago that they'll never be touched by human feet. ☾ Nonetheless, we're not truly separate. Interactions between Earth and the cosmos are continuous. In fact, everything is so interconnected, the links so intimate, that the universe's emissaries pay continuous courtesy calls on our bodies.

The obvious ambassador is light itself, whose particles (photons) bring the electromagnetic force here from distant places. The night sky would be dark if photons created in remote empires weren't continuously touching our retinas. Air's near-total transparency to electromagnetic radiation at visible wavelengths lets us see these objects. Our atmosphere dims stars by a barely-perceptible one-third of a magnitude compared to their brightness in space. Translation: What we view from an unpolluted site is a true representation of the cosmic energy flux at visual wavelengths.

Even though it's invisible to our eyes, some of the universe's infrared energy can be detected by sensory receptors in our skin — as heat. The Sun's warmth is obvious and welcome, while the Moon directs infrared our way as well. Thanks to its hot sunlit surface, each Full Moon temporarily warms our lower atmosphere by 0.04° Fahrenheit — like a giant bathroom heater whose rays are beamed in our direction.

Heat from beyond the solar system is measurable but harder to perceive. Raise your palm toward Arcturus, the brightest springtime star. Feel anything? Well, at least you tried. This giant yellow-orange sun warms your hand to the same extent as a candle located 3 miles (5 kilometers) away.

Some of the incoming material from space does not stop at our retinas or skin. Neutrinos, omnipresent fundamental particles, originate from nuclear fusion inside stars and travel at near light-speed. They have no problem passing through solid objects. It would take a lead wall 1,000 times thicker than the Earth-to-Pluto distance to stop the average neutrino. A trillion pass through your body each second. At night, most come up from below your chair and exit the top of your skull after having zipped through the entire planet in 1/20 of a second. By day, they mostly radiate down from the Sun, enter your head, and exit the soles of your feet.

EACH FULL MOON temporarily warms our lower atmosphere by 0.04° F.

Because neutrinos rarely interact with matter, we don't feel them — even though their passage through our brains may explain any sudden craving for Chinese food. In short, they're harmless.

The same can't be said for muons. They originate 30 miles (48 km) up when cosmic rays from supernovae and other violent events strike air molecules. An average of 240 muons penetrate your body per second, each equaling the weight of 207 electrons. They damage material in cell nuclei and are responsible for some of the spontaneous tumors that have forever plagued the human race.

Other potential troublemakers include magnetars, which we'll explore this summer. One of these tiny stars, lying on the far side of our galaxy, sent a huge burst of energy our way December 27, 2004, followed by a lesser outburst November 3, 2005. Both released more power in a quarter of a second than the Sun emits in 100,000 years.

The resulting gamma rays swept past Earth, knocked spacecraft detectors offscale, caused an aurora, and interfered with radio communications. If you got a sudden yen for chicken with broccoli last November, it was from the extra particles that flashed through your brain.

Most theorists now believe dark matter passes through us in the form of neutralinos — a theoretical type of weakly interactive massive particle that almost never hobnobs with Earth's baryonic material (the stuff that composes your body). Nonetheless, particles like neutralinos exert a gravitational influence and make our galaxy spin as if it were a solid disk. They glue clusters of galaxies together. Neutralinos may explain why Andromeda and the Pinwheel, our two spiral galaxy companions, don't partake of the universe's expansion and leave us for the wild black yonder.

Astronomers back away from the "independent Earth" paradigms that dominated 19th- and 20th-century thought. No longer are we sure our oceans arose without external help from impacting comets, or that amino acids — the precursors to life — developed independently on Earth rather than coming from visiting meteors and comets. We now attribute life's evolution to periodic impacts and space radiation that leaks through our helpful, but not impenetrable, magnetosphere.

Bottom line: Island Earth isn't that much of an island after all. Emissaries from distant places have always been with us. And they are with us, each of us, now. A

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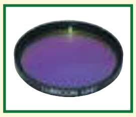

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{ GLENN CHAPLE'S OBSERVING BASICS }

BY GLENN CHAPLE

Go public

This year, National Astronomy Day occurs May 6. The theme of this annual cosmic-fest is "Bringing astronomy to the people." Astronomy clubs will host public star parties with that goal in mind. Astronomy Day always falls on the Saturday between mid-April and mid-May that's closest to the First Quarter Moon. What better way to bring astronomy to the people than to transport them telescopically to this rugged, cratered world?

I feel dismayed whenever I learn of a public star party that's held on a moonless night — especially if it's being planned for children. Big mistake! The party hosts deprive their audience of arguably the most spectacular telescopic sight the night sky has to offer. I rarely hear someone gasp in awe when viewing the Andromeda Galaxy (M31) through my telescope. But the Moon? *Awesome! Fantastic! Wow!*

Would a musician compose a symphony without including at least one rousing musical piece? Of course not! The Moon should be the overture — a spectacular opening to your star-party symphony.

In addition to the "wow" factor, there's a practical reason for selecting the Moon as a star party's opening act. It's an easy-to-view telescopic sight. Many beginners don't know how to look through a telescope.

On those infrequent occasions when I've had to conduct a star party on a moonless night, I've watched them struggle even to see a bright planet like Jupiter. Some position themselves a foot away from the eyepiece, squinting helplessly. Others lurch forward, crunching an eye into the telescope. These mishaps are largely avoided when the Moon is in view. Its light fills the eyepiece — a friendly guide that leads novices to the proper viewing position.

If you're planning a public star party for Astronomy Day and haven't yet set an agenda, here's a suggested schedule:

JUPITER WILL APPEAR bright in the evening sky during Astronomy Day star parties May 6, just 2 days after the planet reaches opposition. NASA/JPL/SSI

Act one: indoor introduction

Around sunset, kick things off with a brief indoor introductory session. A slide or *PowerPoint* presentation provides the audience with pointers on how to look through a telescope and introduces people to the cosmic sights they'll be exploring.

Before sending everyone outside, hand out a flyer listing astronomy resources for the novice (such as *Astronomy* magazine and Astronomy.com). If you contact *Astronomy* at least 6 weeks in advance of any public star party you're planning, we'll send you beginner-friendly handouts.

Act two: the star party

It's show time, so give them that grand overture — the Moon. Select a magnification that affords a comfortable view of the entire lunar disk. Then, let your telescope weave its magic. No need to lecture — the Moon says it all.

Once everyone has "ooh-ed" and "ah-ed" at the Moon, take a short break, then assemble everyone for a star and constellation orientation. Begin with Regulus, that bright star near the Moon. From there, go to the Big Dipper, riding high overhead. Show how the Pointer stars lead the way to Polaris, while the Dipper's handle lets us "Arc to Arcturus," then "Speed to Spica." Direct their attention to Capella and the "Twin" stars Castor and Pollux, slowly setting in the west, then move northeast to Vega, forerunner of summer's legion of stars. Finally, point out two bright "stars" — Saturn and Jupiter.

Your audience will marvel at the sight of Jupiter and its Galilean moons strung out to the sides like four cosmic pearls. Saturn and its rings will garner as many gasps of amazement as the Moon did.

Why start with the Moon and planets as targets? Well, May skies darken at a late hour, and younger attendees may have to leave early. Diehards are more likely to appreciate deep-space objects.

When I host a star party, I bring out the "heavy artillery" — a 10-inch Dobsonian-mounted reflector. However, I don't want anybody going home with the idea that they need a big telescope to see night-sky wonders. If possible, I add a small-aperture telescope to the mix. It's always gratifying when someone peeks into the eyepiece of my 10-inch Dob and exclaims, "Jupiter looked almost as good in that little scope over there as it does in this big one!"

Whether conducted on Astronomy Day or another time of year, a well-planned star party is a wonderful way to bring astronomy to the people.

Next month: a 2-billion-year glimpse into the past. Clear skies! ■

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About Vixen

Vixen astronomical products have been treating their owners to the delight of the night sky since 1949. Always respected by quality minded amateurs, Vixen today offers some of the latest technology encased in the solidity of the past. Take the "goto" SPHINX mount and STAR BOOK; a sturdy German equatorial mount for all types of scopes combined with the first electronic star chart hand-controller. The SPHINX is just one example of Vixen's ingenuity on display at Certified Stocking Vixen Dealers and in stock for you to take home and enjoy tonight.

GP-D2 Equatorial Mount

Deluxe Equatorial Mount

Geared for those seeking a portable, high-precision mount for astrophotography or simply visual observing, the GP-D2 is the perfect platform for more than just Vixen telescopes! Accurate tracking is achieved with dual 144-tooth brass worm wheels and gears. The R.A. worm is machined to 0.001 mm tolerance for accurate tracking, and all worm gears are individually inspected before assembly in Japan. Die-cast aluminum pares the weight of the GP-D2 down to 18.7 lbs. yet the design permits a carrying capacity of 22 lbs. Manual slow motion controls are provided.

R200SS 8" f/4 Richfield Newtonian

Advanced Imaging & Visual

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Recommended Accessories

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5
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"Vixen's newest go-to mount is a winner." — Astronomy

SPHINX mount with its Internet upgradable STAR BOOK controller, is the culmination of a decade of design experience. SPHINX responds nimbly and precisely to your commands due to its lightweight design with low-rotational momentum. STAR BOOK is striking with its 4.7" LCD screen and powerful CPU that produces localized star charts with Constellations, "goto" menus for 22,725 celestial objects: Messier, NGC/IC, Solar System, stars, and more. Auto-guider port works with SBIG guiders. Mount is controllable through popular planetarium programs such as *TheSky6* (*Serious* or *Pro*) and *Starry Nights* (*Pro* or *Pro Plus*).

The Reviews are In: "A telescope mount for the 21st century"

Astronomy magazine, November 2005

- ◆ "The Star Book is so easy to operate it flirts with user-interface perfection ... ."
- ◆ "As it stands now, the Sphinx is by far the easiest-to-use go-to mount."
- ◆ "Those interested in imaging should give this mount consideration."
- ◆ "The Sphinx is an extraordinary value because this amount of periodic error is normally encountered only in mounts 4 or 5 times its cost."
- ◆ "More good news: The mount is terrific."
- ◆ "To its credit, the screen worked well even at low temperatures — I subjected it to a test at -15° Fahrenheit (-26° Celsius) one night... ."

Recommended Accessories

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for both hemispheres

Aluminum Case

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Includes half-pillar pouch.

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ED80Sf 80mm f/7.5 APO Refractor

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Recommended Accessories

SX Camera Adapter

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{ PHIL HARRINGTON'S BINOCULAR UNIVERSE }

BY PHIL HARRINGTON

Big Dipper, part one

"Look, there it is! That's the Big Dipper!" Remember that cry of excitement when you recognized those seven stars for the first time? It could have been decades ago, or maybe just last night. Either way, the Dipper quickly became a lifelong friend. It's there every clear night throughout the year to greet us as we venture out into the universe.

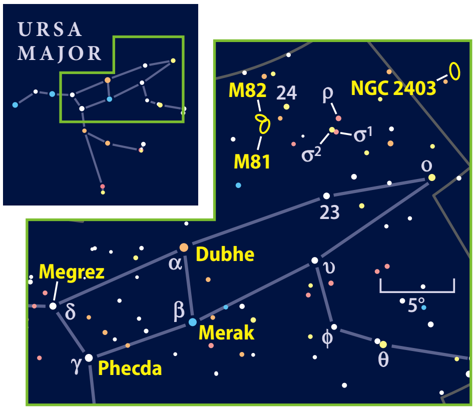
Beginners come to know the Big Dipper as a handy signpost for finding other stars in the sky — "Follow the Pointers to Polaris" or "Arc to Arcturus." This month, we'll use some of the Dipper's visual cues to hunt down binocular targets in the area north and west of the Dipper's bowl. Next month, in "Big Dipper, part two," we'll use its crooked handle to discover other binocular-friendly targets.

Let's first examine each of the four stars that make up the bowl: **Dubhe**, **Merak**, **Phecda**, and **Megrez**. All shine nearly white, except for Dubhe at the bowl's northwest corner, which radiates an orangish glow. That's no surprise because Dubhe is an orange, type-K giant star — larger but cooler than our own Sun.

Using your imagination, draw a line from Phecda, at the bowl's southeastern corner, to Dubhe. Extend that line an equal distance to the northwest until you come to a small right triangle of stars. The star marking the right angle itself is cataloged as 24 Ursa Majoris, while most star charts don't name the other stars.

If you look carefully, you just might spot a faint blur to the triangle's southeast. That's no star but rather the distant spiral galaxy **M81**. Admittedly, finding M81 can be daunting at first, but, give it a chance, and you're bound to spot it.

My first binocular encounter with the galaxy came more than 30 years ago from my parents' suburban backyard in Connecticut. Through 7x35 binoculars, the galaxy's oval shape appeared small and dim but unmistakable. Larger binoculars increase the contrast between the galaxy's bright central nucleus and the dimmer surrounding halo of spiral arms, although the spiral arms themselves are not resolvable.



USE THIS FINDER CHART to locate goodies in the Big Dipper's bowl. ASTRONOMY: ROEN KELLY

Look just north of M81, and try to make out a dimmer splinter of grayish light. If so, you have found **M82**, a dramatic irregular galaxy shown in long-exposure photographs to be erupting from within. 7x35 binoculars also reveal this galaxy's famous cigar shape, provided the night is dark. Unlike M81, however, which shows a brighter core, M82 appears uniformly dim from end to end.

M81 and M82 each lie about 12 million light-years from us, but about 100,000 light-years separate them. Together, they form one of the most striking galaxy pairs in the sky. Other galaxies belong to the M81/M82 group, but, unfortunately, all but one are too faint for our binoculars.

That visible member galaxy lies a good distance away, across the border within the faint constellation Camelopardalis. Comet-hunter Charles Messier (1730–1817) and his contemporaries never saw this spectacular spiral galaxy even though it shines as brightly as M82. With no M classification, it's known today as **NGC 2403**, its entry in the *New General Catalog*.

Hunting down NGC 2403 can be tough, but here's how I do it. Start at M81, and move about 1 binocular field southwest, to a slender triangle formed by 5th-magnitude stars Rho (ρ), Sigma^1 (σ^1), and Sigma^2 (σ^2) Ursae Majoris. This distinctive triangle points toward the west-northwest, right at a lone 5th-magnitude star about a field away. From there, jog another binocular field southwest to a larger right triangle of three 6th-magnitude stars. Our target lies halfway between the triangle's right angle and its southern corner.

Recently, I visited NGC 2403 through my 10x50 binoculars. I just made out its tiny oval glow against the background sky from my backyard here on Long Island. It's a challenging test, but now is the best time of year to give it a go in the evening sky — it crests near our zenith.

Try your luck with each of these three galaxies on the next clear night, and then drop me a line at phil@philharrington.net to let me know how you did. And be sure to visit Astronomy.com this month, where I list a few more challenges in Ursa Major.

Next month, we continue with the Big Dipper's handle and see what it holds in store for our binoculars. Till then, remember: Two eyes are better than one.

ONLINE EXTRA In addition to the objects listed above, three more binocular-friendly targets lie in and around the Big Dipper's bowl. To find them, visit www.astronomy.com/toc.

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IMAGINOVA

Star theft The Milky Way Galaxy has stripped about a million stars from globular cluster Messier 12. Evidence comes from the distribution of star masses in the cluster, say scientists.

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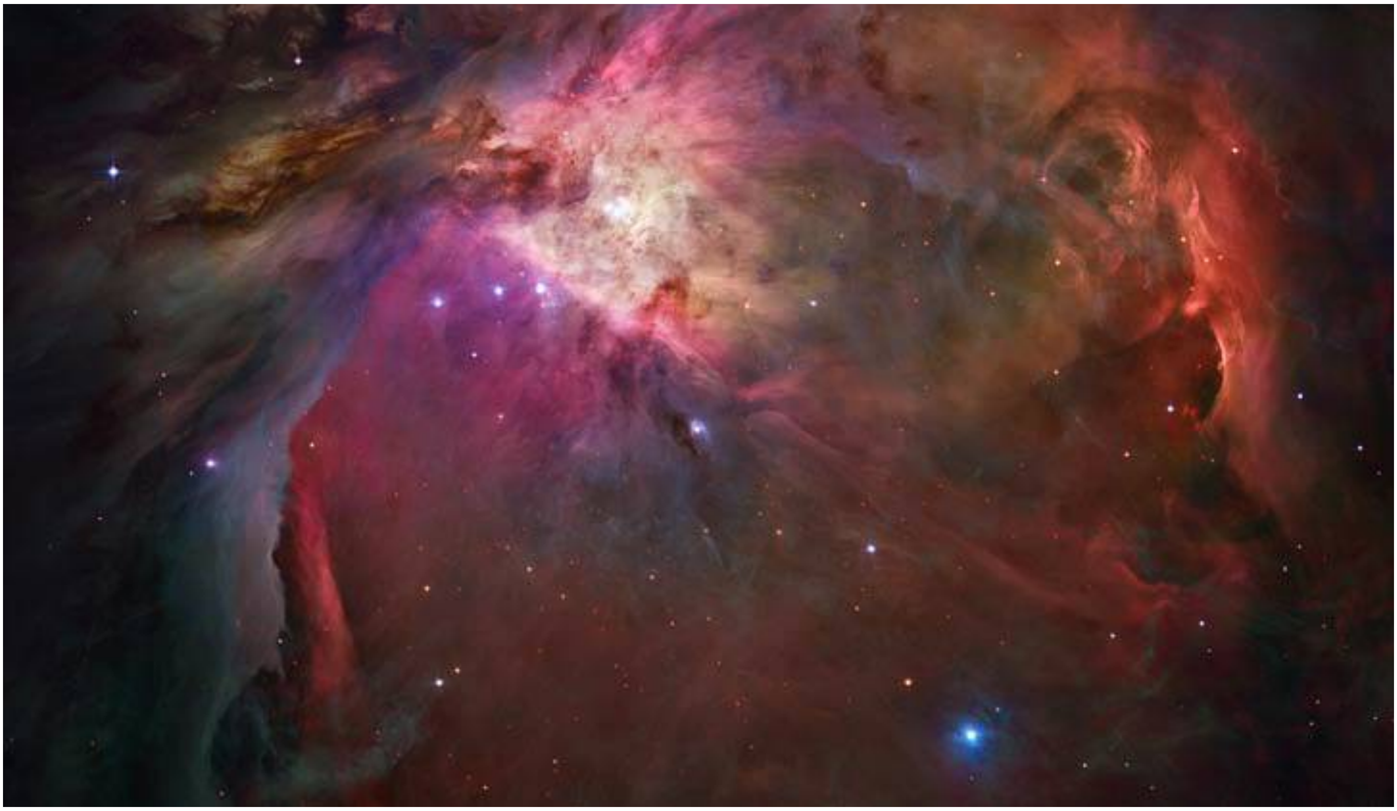

NASA/ESA/M. ROBBERTO

STAR-BIRTH TAPESTRY. Hubble's Advanced Camera for Surveys reveals jets, winds, and an unprecedented catalog of young stars in M42.

26 **Grains grow in Orion proplyds**

27 **Spitzer images a dying star**

28 **High-tech arm lifts space loads**

30 **A larger Cartwheel**

Hubble snaps billion-pixel M42

The most detailed image ever made of the Orion Nebula (M42) is the capstone of the Hubble Space Telescope's largest observational campaign dedicated to star formation.

Astronomers targeted the stellar nursery for 104 orbits in fall 2004 and spring 2005. Using all of Hubble's cameras, astronomers imaged M42 in wavelengths ranging from ultraviolet to infrared. The new mosaic, measuring 33,000 square pixels, contains 520 Hubble exposures as well as ground-based telescope data to fill out the nebula. The image captures 30' of sky, the same angular diameter as a Full Moon. M42 spans about 13 light-years and is 1,500 light-years away.

"The Orion Nebula is the closest star-forming region in which we can observe an entire spectrum of stellar mass, from 40 Suns down to several Jupiter masses," says team leader Massimo Robberto of Baltimore's Space Telescope Science Institute.

A single massive star, Theta^1 C, is almost single-handedly responsible for energizing the gas.

Astronomers have cataloged some 3,200 pre-main sequence stars in the new image, along with a surprise: background galaxies seen through the nebula's wispy glow. — **FRANCIS REDDY**

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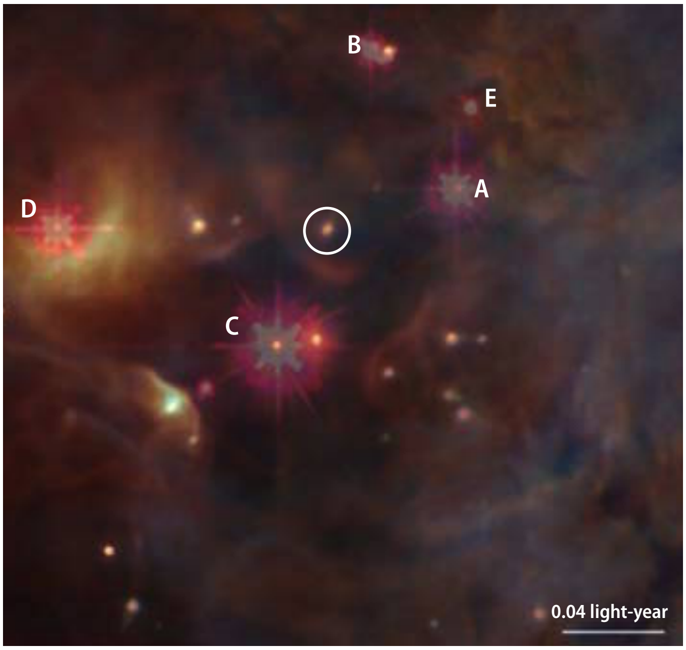
Moon shot The first in a series of U.S. robotic lunar missions passed its preliminary design review February 9. The mission is slated for an October 2008 launch.



NATHAN SMITH, UNIVERSITY OF COLORADO/GEMINI/HST

DUSTY DISK. A proplyd (circled) in Orion's Trapezium grows dust grains despite its harsh environment.

Grains grow in Orion proplyds

New observations reveal dust grains in the Orion Nebula's protoplanetary disks (proplyds) are growing despite bombardment by intense ultraviolet radiation.

Using the Keck I 10-meter telescope and NASA's 3m Infrared Telescope Facility, both atop Hawaii's Mauna Kea, a team led by Keck Observatory's Marc Kassis looked at the spectral signature of silicate dust grains in proplyds amidst the Orion Nebula's Trapezium stars. Ultraviolet light from these massive suns sets the nebula aglow.

The astronomers detected emissions indicating the grains have grown since the disk formed. "You wonder whether these grains will grow enough to start forming planets," says Kassis. Once a dusty disk forms, scientists believe, ultraviolet radiation removes gas. The large particles left behind can interact and form protoplanets. — **F. R.**

Orion's stellar birth cries

Vanderbilt University's Bob O'Dell reports that outflows from stars in Orion's youngest nurseries began only within the last 1,500 years.

Using data from the Hubble Space Telescope, he studied interactions among Orion Nebula shock waves. "When you look closely enough, you see the nebula is filled with hundreds of visible shock waves," he says. They allowed him to determine how long major currents have flowed from the infrared sources known as Orion South and the Becklin-Neugebauer/Kleinmann-Low object. Both sources are star-forming regions buried in the Orion Molecular Cloud behind the famous nebula. — **F. R.**

NASA's budget an "attack on science"

The Bush Administration's proposed 5-year NASA budget trades space research for space shuttle and space station operations and development of the Crew Exploration Vehicle (CEV), say critics.

Lou Friedman, executive director of The Planetary Society, a space advocacy group, called the budget an "attack on science."

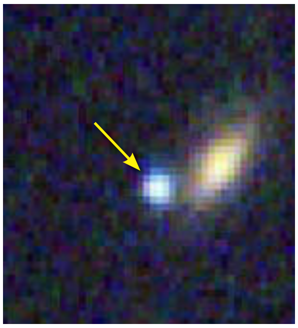
Sherwood Boehlert, chairman of the House Committee on Science, admitted: "This budget is bad for space science, worse for earth science, perhaps worse still for aeronautics."

Programs cuts include two Scout-class Mars missions, a probe to Jupiter's moon Europa, and the Terrestrial Planet Finder satellite. The budget takes 15-percent from all of NASA's Earth- and space-science research, but slashes astrobiology funding by half.

These savings will pay for shuttle missions to complete the International Space Station by 2010 and support CEV development.

"We have decades worth of hard work in front of us just to be able to get back to where we were" at the end of the Apollo era, NASA Administrator Michael Griffin told the House committee February 16. — **F. R.**

SDSS finds 139 new supernovae



SDSS-II COLLABORATION

LIGHT SHOW. SDSS spotted this supernova (arrow) and 138 like it in just 3 months.

Astronomers mining the Sloan Digital Sky Survey (SDSS) for type Ia supernovae struck gold with 139 new finds. Of these, 100 supernovae exploded between redshifts 0.1 and 0.3 (roughly 1 and 3 billion light-years from Earth, respectively). Astrophysicists will use these supernovae to learn more about the nature of dark energy — the mysterious force that's accelerating our universe's expansion.

According to Josh Frieman, coleader of the SDSS search team, only 6 type Ia supernovae with redshifts between 0.1 and 0.3 were known prior to the new study.

Type Ia supernovae serve as "standard candles" because the intrinsic peak brightness of each event is the same. In 1998, two separate groups used such measurements to show the universe's expansion is speeding up. — **LIZ KRUESI**

Faraway metal A gas cloud 6.3 billion light-years away holds the record for the most metal-rich intergalactic cloud — 4 times our Sun's amount.

WHOPPING STARS. **The Milky Way's dust hid one of our galaxy's grandest star clusters.** NASA/NSF/2MASS/UMASS/IPAC-CALTECH AND D. FIGER

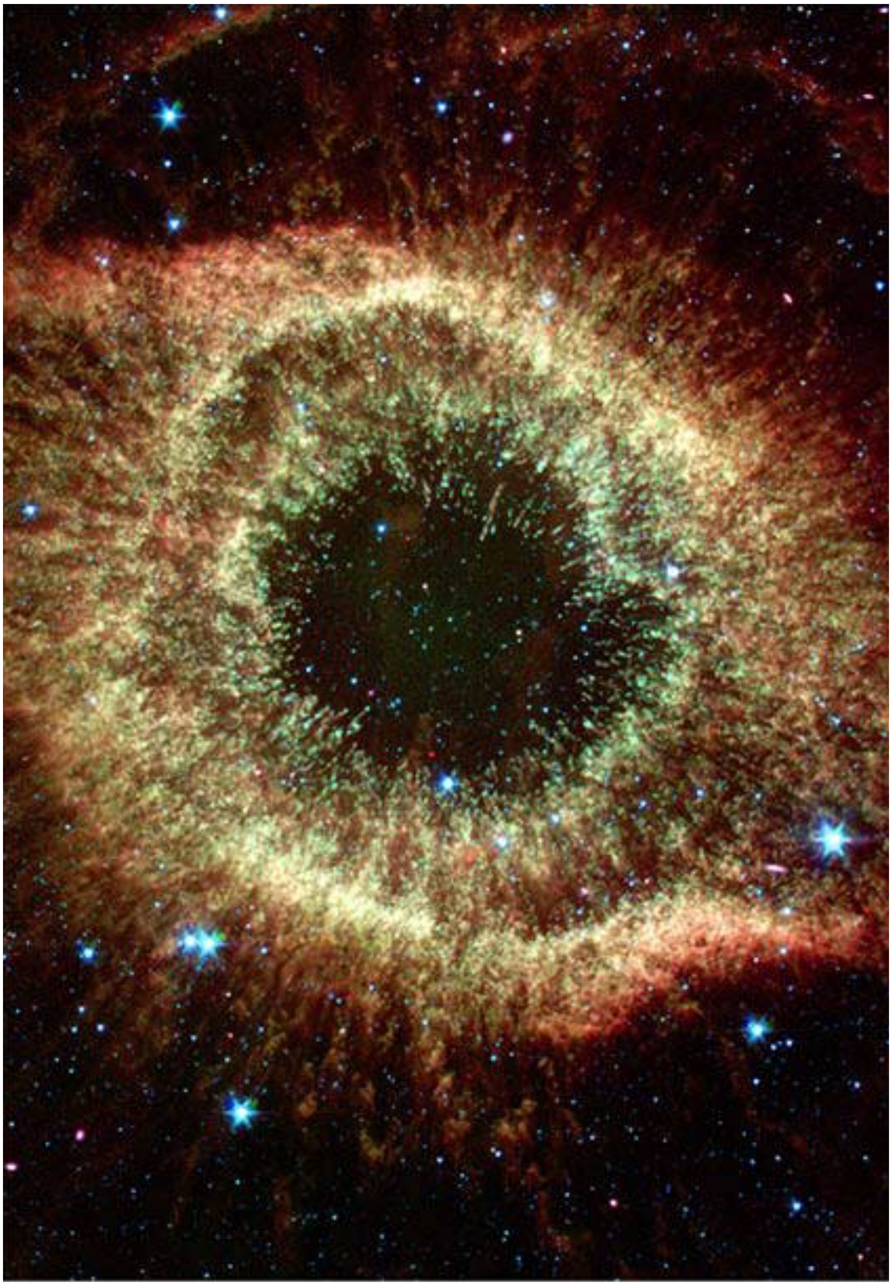
Spitzer finds red supergiant cluster

Astronomers using the Spitzer Space Telescope have located the richest cluster of red supergiants yet found in our galaxy, says Don Figer of Baltimore's Space Telescope Science Institute.

The cluster's 14 red supergiants weigh in at 20 Suns each — so massive they'll eventually explode as supernovae. This one cluster holds 3 times more of these stars than any other single cluster known in the Milky Way. In fact, it contains about 7 percent of the roughly 200 red supergiants known in our galaxy.

"Only the most massive clusters can have lots of red supergiants, because they are the only clusters capable of making behemoth stars," Figer explains. Astronomers who analyzed the cluster's colors using the Infrared Multi-object Spectrograph at Kitt Peak National Observatory near Tucson, Arizona, estimate the cluster contains a total of at least 20,000 solar masses.

The cluster is the first of 130 massive star-cluster candidates Figer and his team will study over the next 5 years using a variety of telescopes, including Spitzer and Hubble. — **LAURA LAYTON**

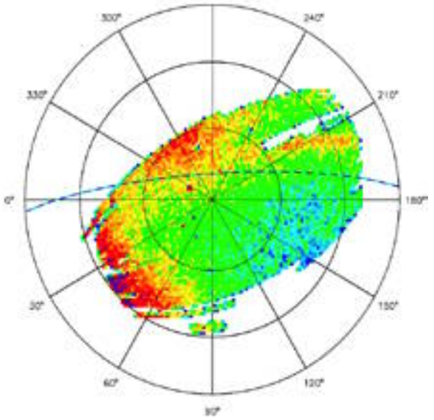


NASA/JPL-CALTECH/J. HORA (HARVARD-SMITHSONIAN CfA)

HEADS AND TAILS. **Bluish-green cometary knots with reddish tails dot the complex structure of the Helix Nebula (NGC 7293) in this Spitzer Space Telescope image.**

Spitzer images a dying star

NASA's Spitzer Space Telescope imaged the Helix Nebula (NGC 7293) in January 2006. Within the planetary nebula's complex structure are cometary knots that appear as bright blue starlike dots. This planetary nebula is one of the closest to Earth at about 450 light-years away in the constellation Aquarius the Water-bearer. It is the result of a dying sunlike star that has shed gaseous shells and disks as it runs out of fuel. This Spitzer image was taken in the infrared part of the spectrum at wavelengths of 3.2, 4.5, and 8.0 microns (here shown in blue, green, and red, respectively). — **L. L.**



STAR PLOT. **The Virgo Overdensity shows up in red in this plot of SDSS data.** MARIO JURIĆ, PRINCETON UNIVERSITY/SDSS-II COLLABORATION

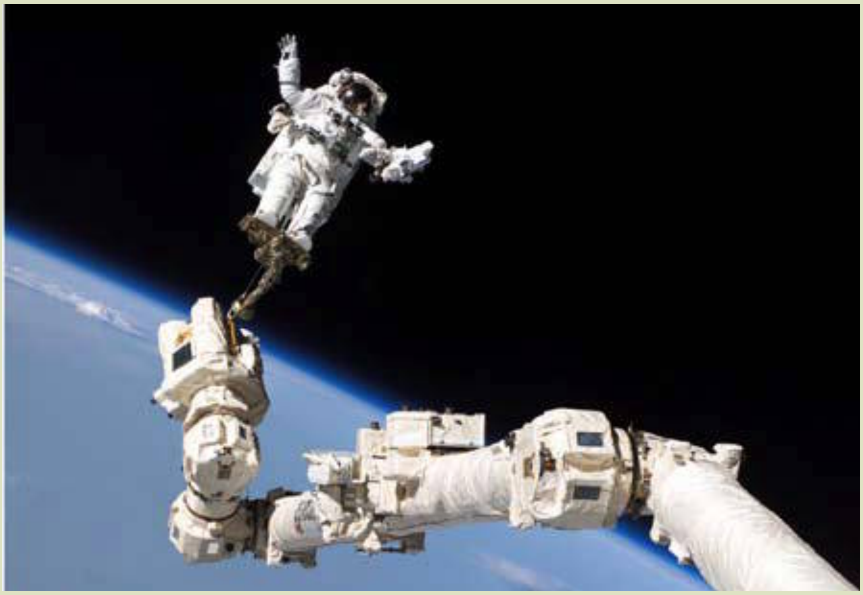
SDSS finds new Milky Way neighbor

Astronomers using a database of some 48 million stars have discovered a faint but huge stellar structure positioned almost directly above the Milky Way's disk. The most likely interpretation, they say, is that this is a dwarf galaxy in the process of merging with our own.

Data from the Sloan Digital Sky Survey (SDSS), which has mapped about one-quarter of the northern sky, allow astronomers to view slices of the stellar halo surrounding the Milky Way in much the same way as doctors use a medical CT scan. The team used the stars' colors and apparent brightnesses to infer their distances.

Viewing slices at progressively greater distances from the Sun, the researchers uncovered a dense, starry swath 30,000 light-years away in Virgo. The patch spans 1,000 square degrees, or more than 5,000 times the angular area of a Full Moon, and contains at least 1 million stars.

"It's a cloud of stars stuck somewhere above the Milky Way," Princeton University's Robert Lupton explains. The find, dubbed the Virgo Overdensity, is "truly a pathetic galaxy," but it spans a greater sky area than any object other than the Milky Way. "It's going to be part of the Milky Way in another million years." **— F. R.**


NASA

LOOK, MOM! **In August 2005, the International Space Station's robot manipulator helped put STS-114 mission specialist Stephen Robinson in the right spot for an experiment installation.**

High-tech arm lifts space loads

When International Space Station (ISS) assembly resumes late this year, one hardware piece will take center stage. This is the Space Station Remote Manipulator System (SSRMS), also called Canadarm2 for the country that built it.

The SSRMS has been attached to the station's exterior for 5 years, but a misleading analogy means few appreciate its true capabilities. Because it's called an "arm," it conjures images of the space shuttle's remote manipulator (Canadarm1).

But Canadarm2 does not perform like a human arm. It's better. The SSRMS is 57.6 feet (17.6 meters) long when fully extended, has 7 motorized joints, can handle large payloads, and can assist with docking space shuttles.

Canadarm2 is the equivalent of two long arms joined at a single elbow joint, with a hand and a wrist at each free end. So, while one hand holds tightly to a handle (which provides electrical power, as well as video and telemetry links), the other is free to work. If the SSRMS needs to work on a region outside its reach, it grabs another handle on the station's exterior, relaxes its grip on the first handle, and swings to the desired area.

In effect, the hand serving as a shoulder switches function with the hand that's grappling hardware. Thanks to attachment points on station modules, the SSRMS can maneuver across much of the station inchworm style.

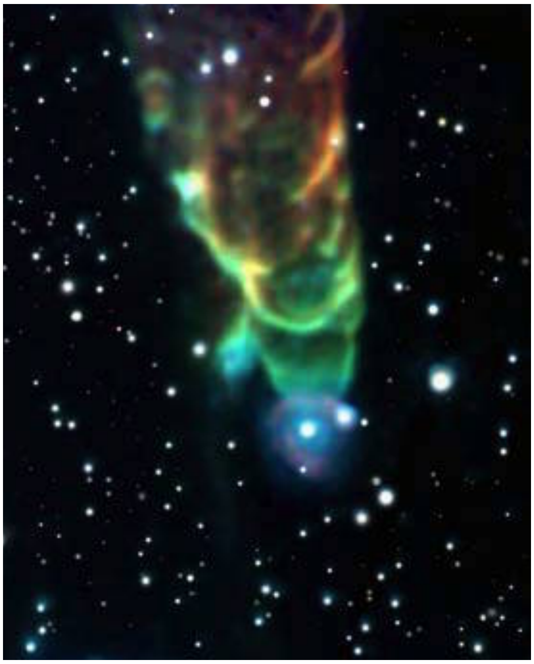
The SSRMS also can travel in style. A wheeled cart called the Mobile Base System, installed as part of STS-111 in June 2002, serves as Canadarm2's work platform. The cart, which also has power/data handles, runs on rails along the station's main structural truss. This moving base gives the SSRMS full access to the space around the station.

Once the shuttle has been cleared for full operations, a sequence of heavy modules and structural elements will begin arriving at ISS. The system will get a full workout placing the pieces into their parking spots.

This free-roving double arm is what makes ISS assembly possible. **— JAMES OBERG**

Oblong Vega

The star Vega's fast spin makes its equator 23-percent wider — and 2,500 K (4,000° F) cooler — than its poles.



NASA/JPL-CALTECH/J. BALLY, UNIVERSITY OF COLORADO

JUST VENTING. **A protostar's outflow creates this odd structure. The star in the center is probably unrelated.**

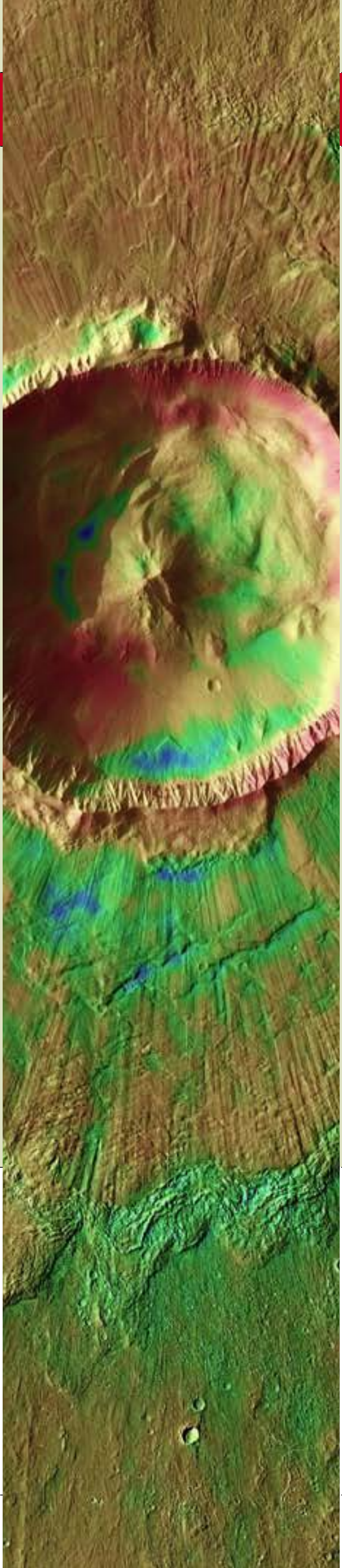
Stellar jet makes a space tornado

Astronomers using NASA's Spitzer Space Telescope imaged an infrared "tornado" in space produced as the jet of a protostar blasted into interstellar gas and dust. The jet, traveling at roughly 360,000 mph (580,000 km/h), heated the material and set it aglow. The jet's wake — similar to the wake behind a boat — created the tornado shape of Herbig-Haro 49/50. Bluer regions at HH 49/50's "tip" are higher energy than the base, which appears redder in this image. Magnetic fields may explain the object's twisted appearance. — **L. K.**

Martian splash

Bacolor Crater lies in Utopia Planitia, a vast, flat region in Mars' northern lowlands. The impact that formed it vaporized the ground and any ice under the point of impact. Shock waves spread outward from the strike point, smashing rocks and heaving the fragments skyward, along with steam and other hot gases. As the shock wave dug deeper, it excavated a bowl-shaped hole in the ground.

This false-color Mars Odyssey THEMIS image shows details as small as 59 feet (18 meters). A thick, probably hot, slurry of mud, water vapor, and rock fragments shot from the growing cavity and fell to the surface. This created an inner ejecta apron. The innermost portion of this layer covered the ground thickly and, near the crater rim, shows signs of having flowed at least sluggishly. — **F. R.**



NASA/JPL/ASU

MUDDY WATERS. **Radial streaks testify that a hot, thick slurry of mud and water shot across the terrain when this crater formed.**

Einstein validated again

Scientists at the National Institute for Standards and Technology (NIST) and the Massachusetts Institute for Technology (MIT) have shown Einstein's famous equation $E=mc^2$ is correct to 0.0000004 percent. The scientists' direct test was 55 times more precise than any previous experiment.

The NIST team measured gamma rays emitted by silicon and sulfur atoms, while the MIT team measured nuclear masses before and after gamma-ray emission. Confirmation of Einstein's famous equation came when the two groups compared their results, which appear in the December 22, 2005, issue of *Nature*. — **L. K.**

NASA/JPL-CALTECH/P. N. APPLETON

GALACTIC BULLSEYE. An ancient collision turned a normal spiral into the famous Cartwheel Galaxy.

A larger Cartwheel

Last year, astronomers discovered extended stellar disks around the Andromeda Galaxy and NGC 300. The trend continues: NASA's ultraviolet-sensing Galaxy Evolution Explorer (GALEX) satellite has revealed a similar disk of faint stars surrounding the famous Cartwheel Galaxy in Sculptor.

The Cartwheel, about 420 million light-years from Earth, is the best known ring galaxy. A brilliant ring gleams with the light of massive, young, blue stars — many weighing 5 to 10 solar masses. Spoke-like formations of older stars appear to connect this bright outer ring with an older inner ring surrounding the galaxy's nucleus.

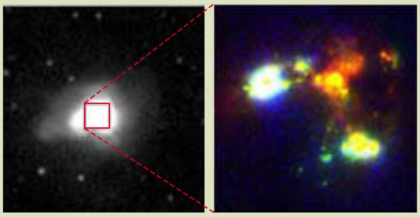
Previously, scientists believed the ring, itself large enough to encircle the Milky Way, marked the Cartwheel's outermost edge. But Phil Appleton of the California Institute of Technology in Pasadena says the latest GALEX observations show a faint disk extending twice the ring's diameter. This makes the Cartwheel about 2.5 times the size of our galaxy.

About 100 million years ago, a small galaxy plunged straight through the disk of a normal spiral galaxy and sparked an expanding burst of star formation. "The dramatic plunge has left the Cartwheel Galaxy with a crisp, bright ring around a zone of relative calm," Appleton says. He presented his GALEX findings at the American Astronomical Society meeting in Washington in January. **— F. R.**

Old galaxy provides new clues

Astronomers using NASA's Far Ultraviolet Spectroscopic Explorer (FUSE) have made the first direct measurements of ionizing radiation leaking from a dwarf galaxy. This observation provides a clue to how — and when — the universe's Dark Ages ended and the first stars shone. The first stars made the universe transparent by ionizing gas clouds.

The team, led by Nils Bergvall of the Astronomical Observatory in Uppsala, Sweden, studied Haro 11, a dwarf galaxy undergoing star formation. The researchers found between 4 and 10 percent of the ionizing radiation the young, hot stars produce is leaking into intergalactic space.



ESO/D. KUNTH ET AL.

ILLUMINATING GALAXY. Dwarf galaxy Haro 11 (left) leaks high-energy radiation from its star-forming region (right) into intergalactic space.

Scientists think quasars in the early universe contributed to the end of the cosmic Dark Ages following the Big Bang. The quasars' high-energy radiation possibly stripped electrons away from intergalactic material and ionized it. But the FUSE observations show that regions of early star formation also may have contributed to the Dark Ages' end. **— L. K.**

BRIEFCASE

Hypergiants may have hyperdisks

Astronomers using the Spitzer Space Telescope have found evidence that stars up to 70 times the Sun's mass may harbor disks of dusty debris. The researchers found infrared signals from a possible disk around stars R66 and R126 in the Large Magellanic cloud. The study appears in the February 10 *Astrophysical Journal.* **— F. R.**

Most Milky Way stars are single

Charles Lada of the Harvard-Smithsonian Center for Astrophysics in Massachusetts says most (80 percent) of the rare, bright O- and B-type stars come in groups of two or more. But the more common low-mass stars like the Sun and M-class dwarfs prefer to circle the galaxy alone. Lada's study will appear in *Astrophysical Journal Letters.* **— F. R.**

Satellite galaxies warp Milky Way

A warp in the Milky Way's neutral hydrogen disk has puzzled astronomers since its 1957 discovery. Now, Leo Blitz at the University of California, Berkeley, and colleagues believe they've hit on an explanation involving the Milky Way satellites — the Large and Small Magellanic Clouds.

"We could describe the warp by three modes of vibration, or three notes, and only three," Blitz says. The warp seems to form as a result of three different types of vibration: an up-and-down flapping of the disk's edge; a saddle-shaped oscillation; and sinusoidal waves. These three "notes" occur at frequencies 64 octaves below middle C.

What could excite these oscillations? Martin Weinberg, a theorist at the University of Massachusetts, Amherst, created a computer model of the Magellanic Clouds traveling through the Milky Way's dark-matter halo. He found this motion excites a vibration at the center of the dark-matter halo, which, in turn, makes the Milky Way's disk oscillate in three distinct modes. The disk's combined motion during the Magellanic Clouds' 1.5-billion-year orbit resembles the edges of a tablecloth flapping in the wind.

Similar dynamics may explain the warped disks of other galaxies, Blitz says. The study will appear in an upcoming issue of *The Astrophysical Journal.* **— F. R.**

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BLOWING BUBBLES. The N44 superbubble may be an important clue for astronomers seeking a source of space's million-degree gas. GEMINI OBSERVATORY/TRAVIS RECTOR, UNIVERSITY OF ALASKA, ANCHORAGE

Supernovae may heat space

A 250-light-year-wide hole in the N44 superbubble complex in the Large Magellanic Cloud suggests stars are key contributors to the hot, diffuse gas that fills space.

Outflows from a clutch of massive stars at N44's center aren't powerful enough to form the hole, say astronomers. But many of these short-lived stars must become supernovae. Remnants of these explosions could sculpt the cloud's cavity.

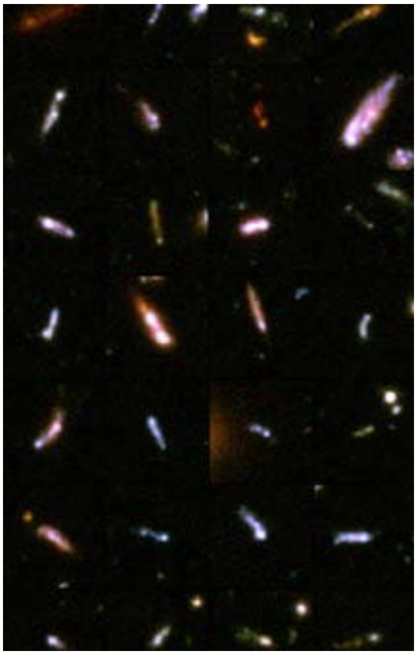
Sally Oey of the University of Michigan says million-degree, X-ray-emitting gas escaping N44 validates this idea. "This is the only object of its kind where we have actually seen it happening," she says. — **MATTHEW QUANDT**

Black holes feed off mergers

Two teams of astronomers analyzing the Hubble Ultra Deep Field (HUDF) report evidence that black holes grow through galaxy mergers.

One group, led by Amber Straughn of Arizona State University (ASU), looked for galaxies in the early stages of merging with tidal tails from gravitational interactions ("tadpoles"). None of 165 HUDF tadpoles showed brightness fluctuations, which suggests dust shrouds our view of the black holes.

Seth Cohen, also of ASU, studied 45 objects at a later stage, when dust was less prevalent. They showed dramatic brightness changes, which means the galaxies likely contain feeding black holes, he says. — **L. K.**



NASA/A. STRAUGHN, S. COHEN, R. WINDHORST (ASU), AND THE HUDF TEAM (STScI)

GALACTIC TADPOLES. These recently merged HUDF galaxies hide their black holes in shrouds of dust.

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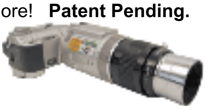

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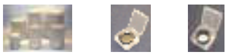

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{ EXTRAGALACTIC ASTRONOMY }

What happens when black holes collide?

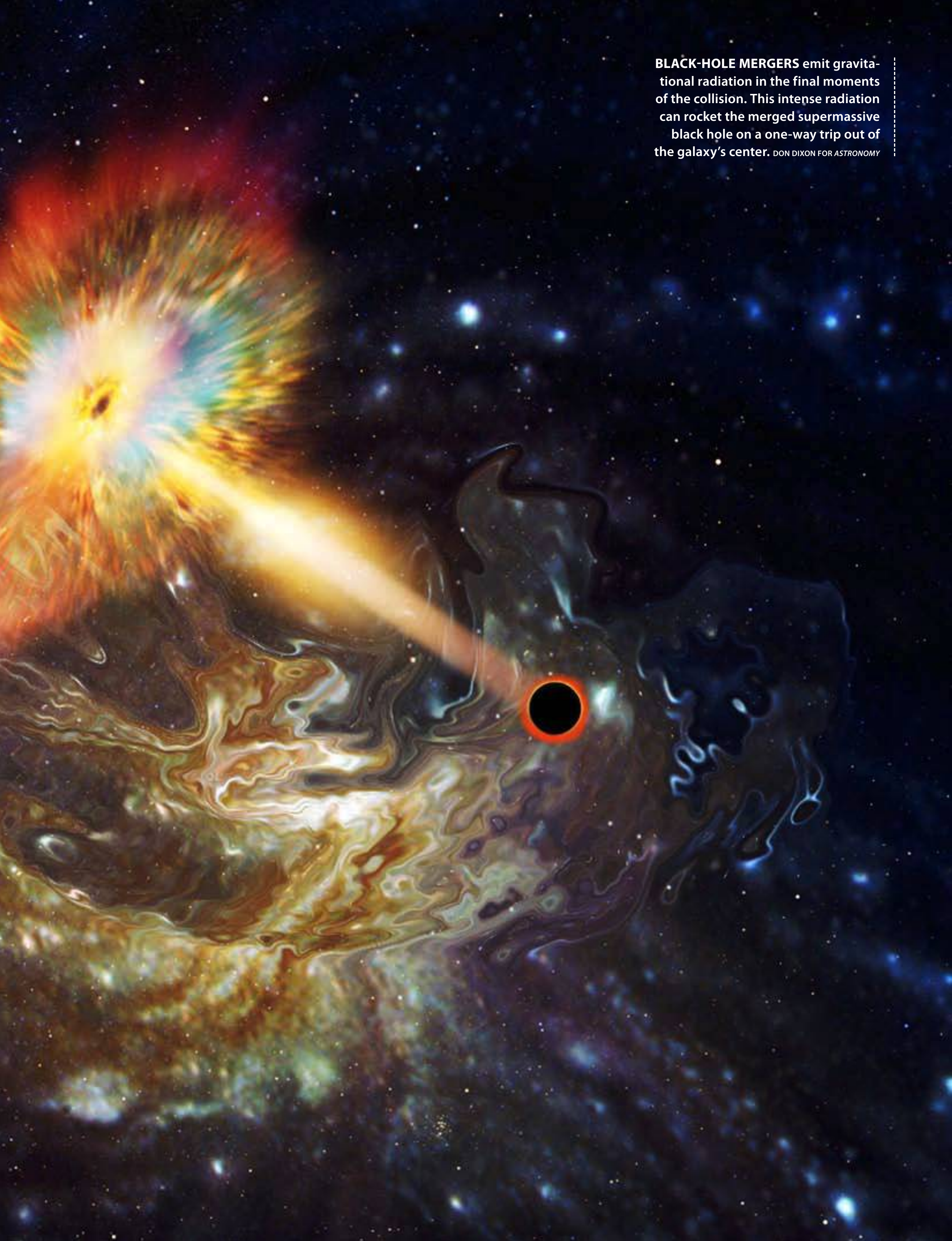
Gravitational waves slingshot them outside galaxies on a frantic, deep-space journey. /// **BY STEVE NADIS**

It may be one of the universe's ultimate "kicks": As two black holes spiral toward each other and coalesce into one, the final black hole is shot out of the galactic center — and possibly out of the galaxy itself — by a gravitational-wave rocket.

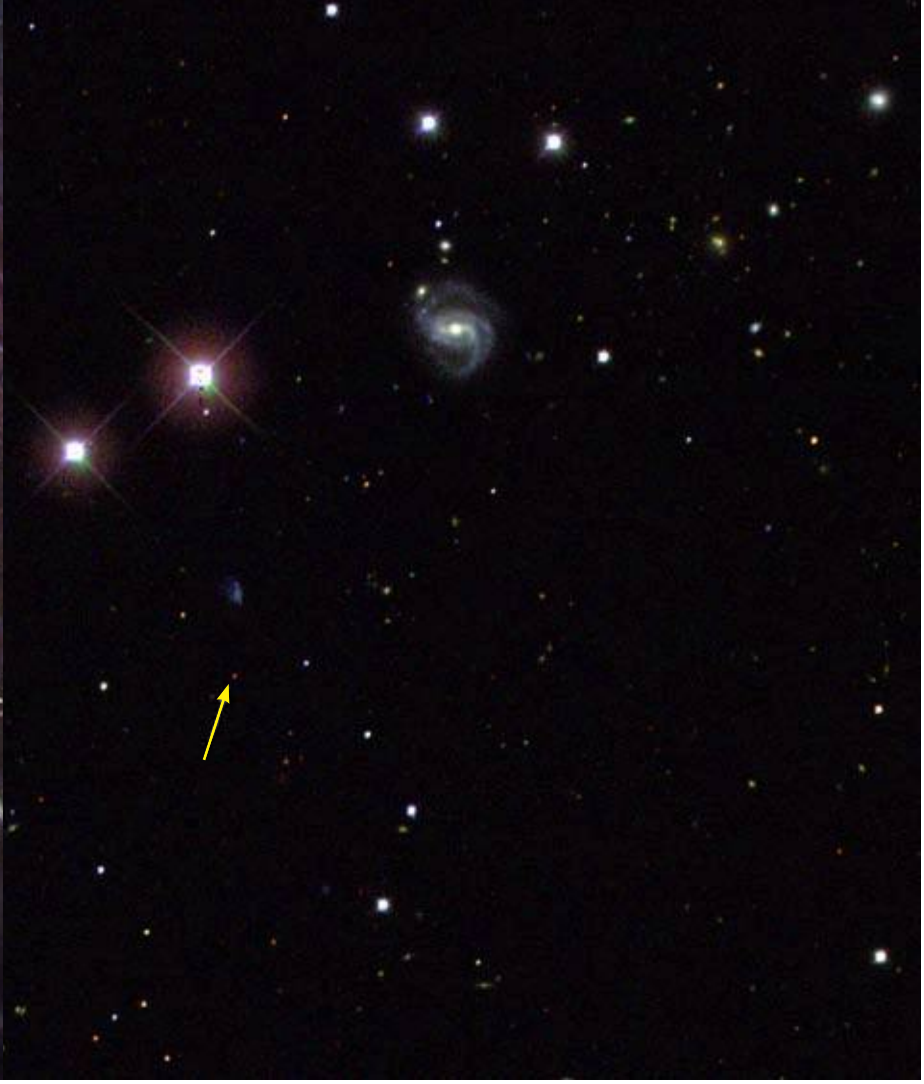
This recoil is a consequence of Einstein's theory of general relativity. In the stage just before two black holes merge, they emit gravitational waves, which can be asymmetric. Once the black holes take the final plunge, these unbalanced waves can fling the product out of the galactic center.

Although the effect hasn't been experimentally observed yet, astronomers have discussed it for more than 2 decades. The subject heated up in 2004 when Marc Favata of Cornell University in Ithaca, New York, Scott Hughes of the Massachusetts Institute of Technology, and Daniel Holz of the University of Chicago (now at Los Alamos National Laboratory) presented the most detailed calculations yet of recoil velocities. Their study in *The Astrophysical Journal Letters* initiated a spate of papers about black hole kicks.

Steve Nadis, *a frequent contributor of* Astronomy, *writes often about the wild things in the cosmos.*



BLACK-HOLE MERGERS emit gravitational radiation in the final moments of the collision. This intense radiation can rocket the merged supermassive black hole on a one-way trip out of the galaxy's center. DON DIXON FOR *ASTRONOMY*



THE FEEBLE LIGHT **from a redshift 4.75 quasar (arrow) took a bit less than 12.5 billion years to reach our eyes. In this image, we see the quasar when the universe was just 1.5 billion years old. Physicists are learning how the supermassive black hole that feeds the quasar got so big early in the universe.** SDSS COLLABORATION

Researchers are now trying to refine velocity estimates, determine the fates of black holes expelled from galactic cores, and see if this phenomenon influences the building of supermassive black holes weighing a million to a billion times our Sun's mass.

How black holes get their kicks

The Sloan Digital Sky Survey has discovered quasars — supermassive black holes shooting out high-speed jets of material — from the universe's early times. Theorists are hard-pressed to explain how black holes can reach a billion solar masses before the universe is 900 million years old — the age of the oldest Sloan quasars. Black hole kicks add yet another wrinkle.

Astrophysicists know cosmic structure grows through a hierarchical process — small building blocks combine to make bigger units. If black holes also grow through mergers and get kicked out as a result, how can they reach the mammoth stature of the Sloan quasars so quickly? Do they grow through mergers or by accretion — feeding on gas and stars within their gravitational reach? "It all depends on the size of the kicks," says University of Cambridge astronomer Martin Rees.

Scientists are searching for binary black holes locked in a close dance. So far, astrophysicists have observed two black holes in the same galaxy, although they're not close enough to begin spiraling together. Indirect evidence shows binary black holes do exist, claims Hughes: "Almost all large galaxies contain black holes, and galaxies merge like mad — especially a couple of billion years ago." It's logical that binaries would form, he says, but they'd be hard to see. "We're talking about two incredibly small bodies separated by a parsec," or 3.26 light-years.

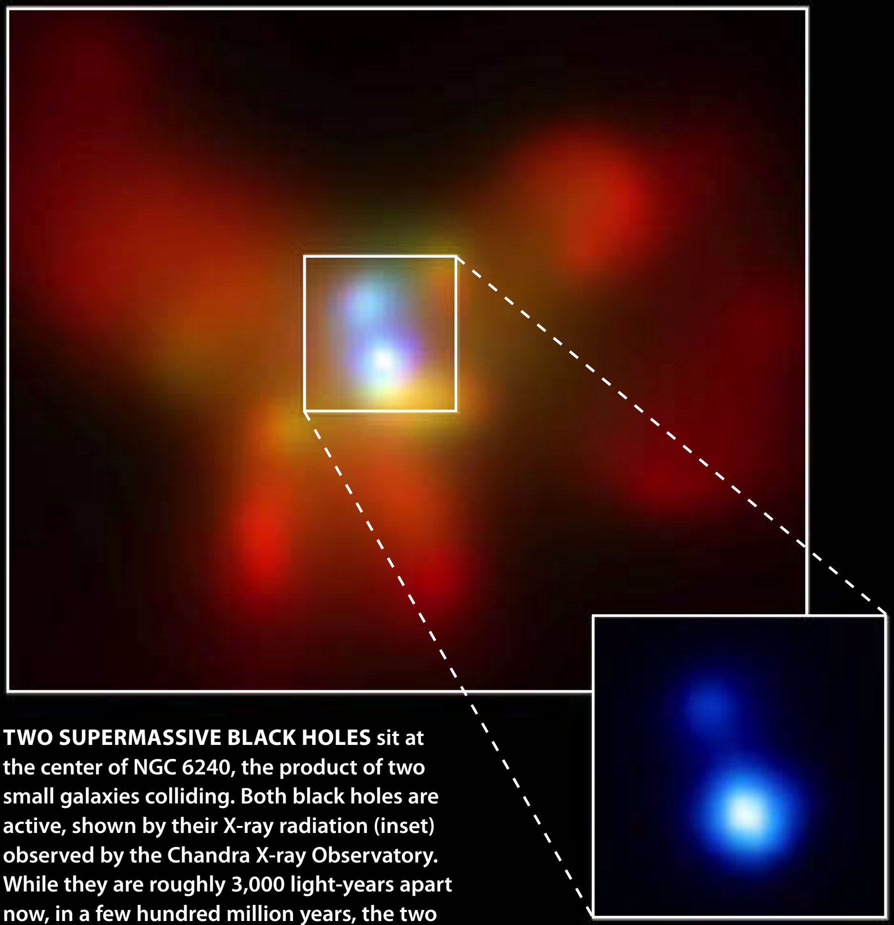
At that separation, the black holes are still too far apart for gravitational-wave emissions to become significant. But if the binary is embedded in a field of stars, gravitational interactions between black holes and stars can slingshot stars out of the area. This drains energy from the entire system, which allows the black holes to get closer. As they do, their orbital speeds increase and gravitational waves turn on, ridding the system of even more energy. The process accelerates and culminates in the two black holes melding into one.

Just before they collide, differences in the black holes' gravitational-wave emissions, which stem from differences in mass and spin, lead to the final recoil. Recoil velocities, conclude Favata, Hughes, and Holz, are unlikely to exceed 310 miles per second (500 kilometers per second).

What happens next depends on the sizes of both the kick and host galaxy. Galaxies forming in the early universe — protogalaxy halos — are weakly bound gravitationally and, therefore, have escape velocities of only about 6 miles/s (10 km/s), according to Hughes. Dwarf galaxies have a stronger gravitational pull, and so they have escape velocities of a few hundred miles per second. Large galaxies like the Milky Way have escape velocities of 310 to 930 miles/s (500 to 1,500 km/s). When the recoil exceeds the galaxy's escape velocity, the gravitational pull can't retain the black hole.

After leaving the galaxy, the black hole would travel at about 190 miles/s (300 km/s), says Piero Madau of the University of California, Santa Cruz. It would join other "wandering black holes," eluding detection. "If they're not shining [from their accretion disks], it's hard to know where to look," says Madau. Current technology is not advanced enough to see black holes via gravitational lensing — the only way to detect them.

When the recoil exceeds the galaxy's escape velocity, the gravitational pull can't retain the black hole.



TWO SUPERMASSIVE BLACK HOLES sit at the center of NGC 6240, the product of two small galaxies colliding. Both black holes are active, shown by their X-ray radiation (inset) observed by the Chandra X-ray Observatory. While they are roughly 3,000 light-years apart now, in a few hundred million years, the two black holes will merge. NASA/CXC/MPE/S. KOMOSSA ET AL.

The notion of unattached black holes drifting unnoticed in intergalactic space is intriguing. As for its significance, says Madau, "It means our census of black holes is incomplete. We haven't accounted for all the massive black holes in the universe because we can see only the ones that are shining."

Population: unknown

Black holes can grow "by stealth" — swallowing matter without radiating — notes University of Colorado astrophysicist Mitchell Begelman. "For that reason, we can't rule out the possibility that black holes outside galaxies contain more mass than black holes inside galaxies."

Although some black holes may not be bound to a galaxy, they're not necessarily lost forever. An analysis by Avi Loeb of Harvard University and Stuart Wyithe of the University of Melbourne found that black holes kicked from a small galaxy would be confined to a larger gravitational system that ultimately makes a bigger galaxy. "These small galaxies are clustered from the beginning — doomed to merge to make a bigger galaxy," says Loeb. "Even if a black hole is ejected, it's still in the game."

Computer simulations performed by Tom Abel of Stanford, Miroslav Micic, and Steinn Sigurdsson, both of Pennsylvania State University, came to this same result. They began with 3,000 dark-matter halos, each with a small central black hole, and watched them interact and evolve from redshift 8 (about 600 million years after the Big Bang) to redshift 1 (some 5 billion years later). "Almost all the black holes get fully kicked out of the halos that formed them," says Abel, but most end up in one galaxy or another. "Ejection may be a common phase in the life history of a black hole," he says. "It goes on this journey and eventually becomes part of a giant black hole."

For black holes nudged from the center, the journey is less spectacular. After a modest kick, a black hole returns to a big galaxy's nucleus after a few orbits, a couple hundred million years later, says David Merritt of the Rochester Institute of Technology.

On the other hand, a small black hole flung to a dwarf galaxy's fringes may orbit "almost forever," says Abel. A black hole's motion is slowed by the gravitational tug of stars — a process called dynamical friction. As the black hole loses angular momentum, it sinks toward the galaxy's center. But dynamical friction is inefficient in a diffuse halo possessing little braking material. In Abel, Micic, and Sigurdsson's simulations, 20 times fewer black holes make it to the center when kick velocities are 80 to 170 miles/s (125 to 275 km/s) rather than 0 to 90 miles/s (0 to 150 km/s). The result is a population of black holes stranded in galaxy halos.

Finding signs of displaced black holes would provide the strongest evidence in support of kicks. "But that's going to be hard to see because it's hard to spot black holes even when you know where to look," says Merritt. The tricky part, notes University of California, Berkeley astronomer Eliot Quataert, is locating the galaxy's center when the active galactic nucleus is offset. "You normally identify the center by seeing the bright light of a quasar," he says.

One possible way to detect a kicked black hole involves radio observations of a jet of material streaming from a black hole. (The jet is actually from the black hole's accretion disk; see "Ask Astro," page 72.) If the black hole was kicked, the jet's path would bend over a million or so years. The problem, says Quataert, is that there could be other causes for a bend, such as a jet hitting a clump of gas in its way. "It would be hard to attribute the bend strictly to a kick."

Black holes gone missing?

Merritt points to some tantalizing circumstantial evidence for kicks: "As we look at ever smaller galaxies, there's a point where you stop seeing black holes." The cutoff occurs when a galaxy's escape velocity drops to about 125 miles/s (200 km/s). This is "just what you'd expect from the estimated size of kicks. Do these smaller galaxies have black holes that no one has been able to see or have their black holes been kicked out?" he asks.

One way to find out is to survey dwarf galaxies. Merritt and colleagues have studied two nearby dwarfs, M32 and NGC 205, in the Local Group. They found M32 bears strong hints of a black hole, whereas the evidence for NGC 205 is inconclusive. "M32 has an escape velocity of about 400 kilometers per second," says Merritt. "You could barely hope to kick out a black hole, and that, apparently, hasn't happened."

ASTROSPEAK

ACTIVE GALACTIC NUCLEI (AGN):
The energetic (active) cores of some galaxies.

ANGULAR MOMENTUM:
Energy of motion of a rotating body; value depends on the body's mass, radius, and spin rate.

DARK MATTER:
27 percent of the universe today; invisible; detected only from its gravitational effects; comprised most of the early universe.

EDDINGTON LIMIT:
A theoretical limit where the force of radiation is equal to the force of gravity in a black hole; named after British astrophysicist Sir Arthur Eddington.

EINSTEIN'S FIELD EQUATIONS:
Describe how matter and energy change the geometry of space-time; part of Einstein's theory of general relativity.

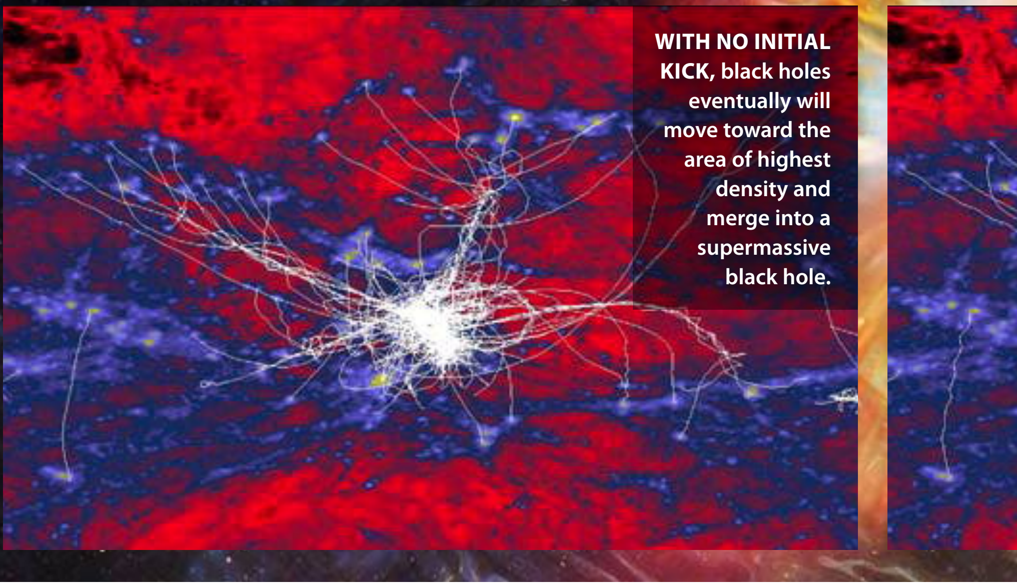
GRAVITATIONAL LENSING:
The distortion or amplification of an object's light due to the presence of a massive object between it and Earth.

QUASARS:
(Abbreviated from "quasi-stellar objects"); the most luminous objects in the universe; thought to be powered by supermassive black holes.

REDSHIFT:
Used as a measure of cosmological distance denoted by the symbol z; as the universe expands, light's wavelength is stretched and its color shifts toward red; today is z=0, at half the universe's age z=1.

STELLAR-MASS BLACK HOLES:
Black holes with masses up to 10 times the mass of our Sun; arise from the collapse of massive stars; the event-horizon diameter is a few miles across.

SUPERMASSIVE BLACK HOLES:
Black holes with masses millions to billions times that of our Sun; the event-horizon diameter is roughly the size of our solar system.



WITH NO INITIAL KICK, black holes eventually will move toward the area of highest density and merge into a supermassive black hole.

BLACK HOLE KICKS can be modeled with computers. In these simulations, performed by Tom Abel, Miroslav Micic, and Steinn Sigurdsson, hundreds of primordial black holes live within dark-matter halos. Each image shows black-hole trajectories (white) over billions of years — from redshift 8.1, when the universe was 600 million years old, to redshift 1, at 6.5 billion years old — based on different initial velocities. Yellow corresponds to high-density areas; blue to mid-density; red to low-density. TOM ABEL/MIROSLAV MICIC/STEINN SIGURDSSON

M32 is the only dwarf galaxy in which astronomers have detected a central black hole. Unfortunately, astronomers can't observe dwarfs in the next closest group of galaxies, laments Merritt. This means astronomers have too small a sample to determine how many black holes are ejected.

Feeding frenzy

Understanding the process of black-hole ejection, Favata says, can help astrophysicists figure out which picture for growing giant black holes — mergers or accretion — is most credible.

The kick phenomenon argues against models in which black holes primarily grow through mergers. "Although mergers can and will happen, they're probably not the main thing," says University of Illinois, Urbana-Champaign astrophysicist Stuart Shapiro. "The current view is that most black-hole growth is due to accretion."

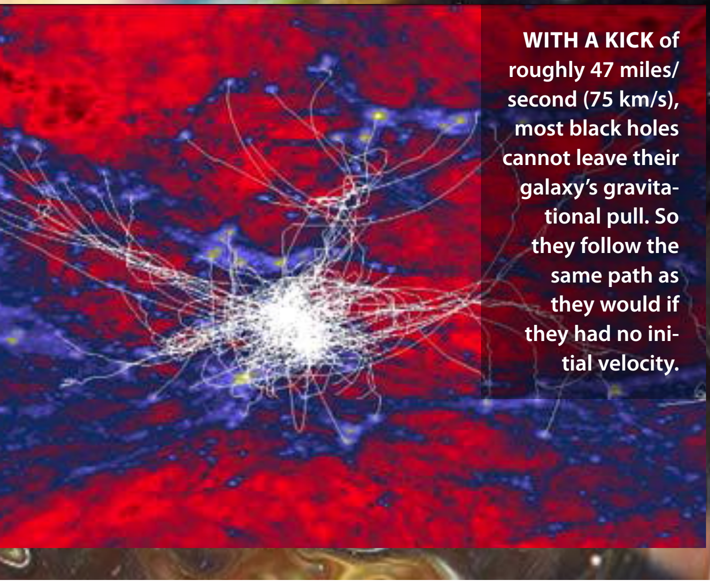
Accretion is an exponential process. A black hole pulls material in by gravity; as the black hole's mass increases, its growth rate increases as well. There's a maximum rate at which a black hole can grow: the Eddington limit. Matter can fall into a black hole only so fast because outgoing radiation pushes against it. Depending on an individual black hole's efficiency of converting matter to radiation, it can double in mass about once every 40 million years, expanding as fast as the Eddington limit allows.

"Exponential growth is the fastest growth we know of, but it may not be fast enough," says Zoltan Haiman of Columbia University. Because of kicks, black holes could get a late start and need an even faster growth spurt called super-Eddington accretion. In this case, a black hole might circumvent the limit by drawing in gas from one direction and sending radiation out in another.

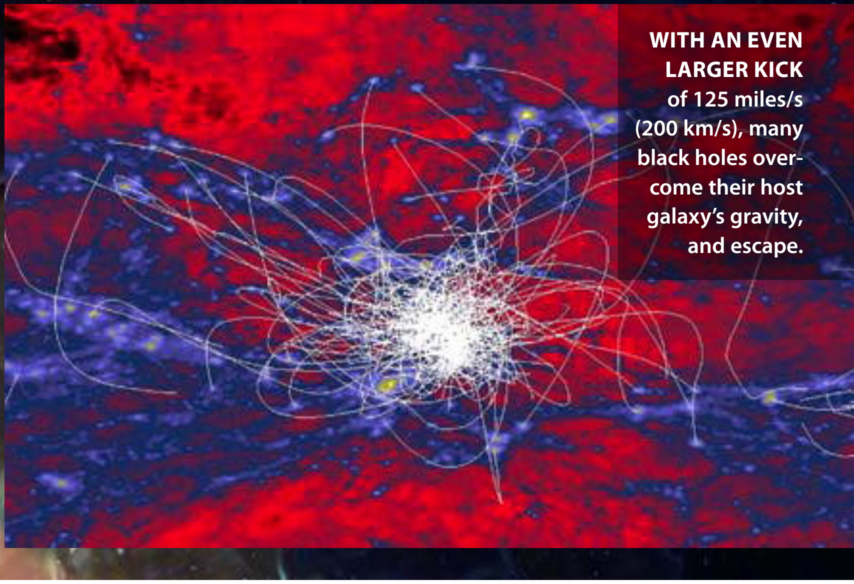
Super-Eddington accretion makes theoretical sense, but Haiman, among others, offers an alternative explanation: In early times, when ejection risks are greatest, black holes are rare. "Suppose you have 100 microgalaxies, only one of which has a black hole," he says. "You can merge the galaxies as before, but they don't have black holes, so there's no kick." Eventually, you'll have a big galaxy with a black hole. When it merges with a black-hole-endowed counterpart, the new galaxy will be big enough to keep its black hole. In this way, adds Quataert, "You can start off with black holes being rare in small galaxies and protogalaxies and end up with black holes in every large galaxy."

Black-hole ballet

Haiman offers several hypotheses to explain the dearth of black holes in the early universe. Perhaps most small galaxies



WITH A KICK of roughly 47 miles/second (75 km/s), most black holes cannot leave their galaxy's gravitational pull. So they follow the same path as they would if they had no initial velocity.



WITH AN EVEN LARGER KICK of 125 miles/s (200 km/s), many black holes overcome their host galaxy's gravity, and escape.

spin too fast for their gas to condense, thereby inhibiting the formation of black holes and stars. Another possibility is molecular feedback: The first quasars emit ionizing radiation that destroys molecular hydrogen in their vicinity. (Molecular hydrogen absorbs heat, and therefore cools gas so that it can collapse to form other black holes.) Observational tests can help determine which idea is right, Haiman says.

The question of how supermassive black holes form will remain a mystery for a while because no experimental solution appears imminent. In the meantime, we need to bear one fact in mind, says Jordi Miralda-Escude of the Institut d'Estudis Espacials de Catalunya: "The black holes are there." So not all black holes could have been kicked out of early galaxies. "Although some black holes may be ejected early on, others won't escape, so the process can continue," Miralda-Escude adds.

> **"Even if a black hole is ejected [from a galaxy], it's still in the game." — *Avi Loeb, Harvard University***

Given the imprecision of kick velocity estimates, Merritt agrees it's possible to accommodate lots of models. "I just want Scott [Hughes] to sit down and do more detailed velocity calculations."

Hughes and Favata plan to do just that. "Right now, there's a factor of 2 uncertainty in our numbers," admits Hughes. The error bar, unfortunately, is big enough to mean the difference between a black hole escaping a small galaxy or not.

Their original computation handled the slow, "inspiral" phase of a merger well, Hughes explains, "But our ability to model the system gets worse as the black holes get closer together." In the next go-round, they hope to improve the accuracy by treating the final "plunge" phase more realistically.

A model by a University of Texas, Brownsville team, headed by Manuela Campanelli and Carlos Lousto, takes a complementary approach. They picked black holes of comparable size — a two-to-one mass ratio — in contrast to Favata, Hughes, and Holz, who selected a "normal" size black hole and a tiny companion to make the calculation easier. Campanelli and Lousto, moreover, are focusing solely on the plunge, starting their simulations when the black holes are just a few hundred miles apart. As with the Hughes group, the error bars are substantial, according to Lousto, due in large part to uncertainties about the initial conditions. To simplify their calculation, Campanelli and Lousto did not take black-hole spin into account. They plan to incorporate spin in future scenarios, as it can influence both kick magnitude and direction.

Making progress

More recently, another group — Luc Blanchet of the Institut d'Astrophysique de Paris, Moh'd Qusailah of the Raman Research Institute in Bangalore, India, and Clifford Will of Washington University in St. Louis — trimmed the error bars of recoil velocities significantly. Their calculations have an uncertainty of 20 percent, which gives the most precise results to date. Even though they focused on the plunge phase, their results match the Hughes group.

Astrophysicists can compute kick velocities for special cases, such as when two black holes with specified masses and spins ram into each other head on. The more general case — black holes of arbitrary mass and spin circling toward each other — is more difficult. Theorists must solve Einstein's field equations without using approximations that make the computational task manageable.

Hughes is confident that "someday, someone will be able to do the full calculation," although he can't say when. It's only been about 5 years since people have confronted the kick problem, notes Saul Teukolsky of Cornell, who is hopeful it can be solved within the next 5 years. In the early 1990s, he adds, "People used to think that if we were clever, we could solve the [black-hole-merger] problem quickly. If not, we could wait until computers were more powerful and solve it by brute force. We now know that we can't do it by brute force alone. We need to be clever, too, and that's the part we haven't quite worked out."

ONLINE EXTRA For recent black-hole findings, visit www.astronomy.com/toc.

{ PLANETARY EXPLORATION }

Saturn's TITAN REVEALS earthlike surprises

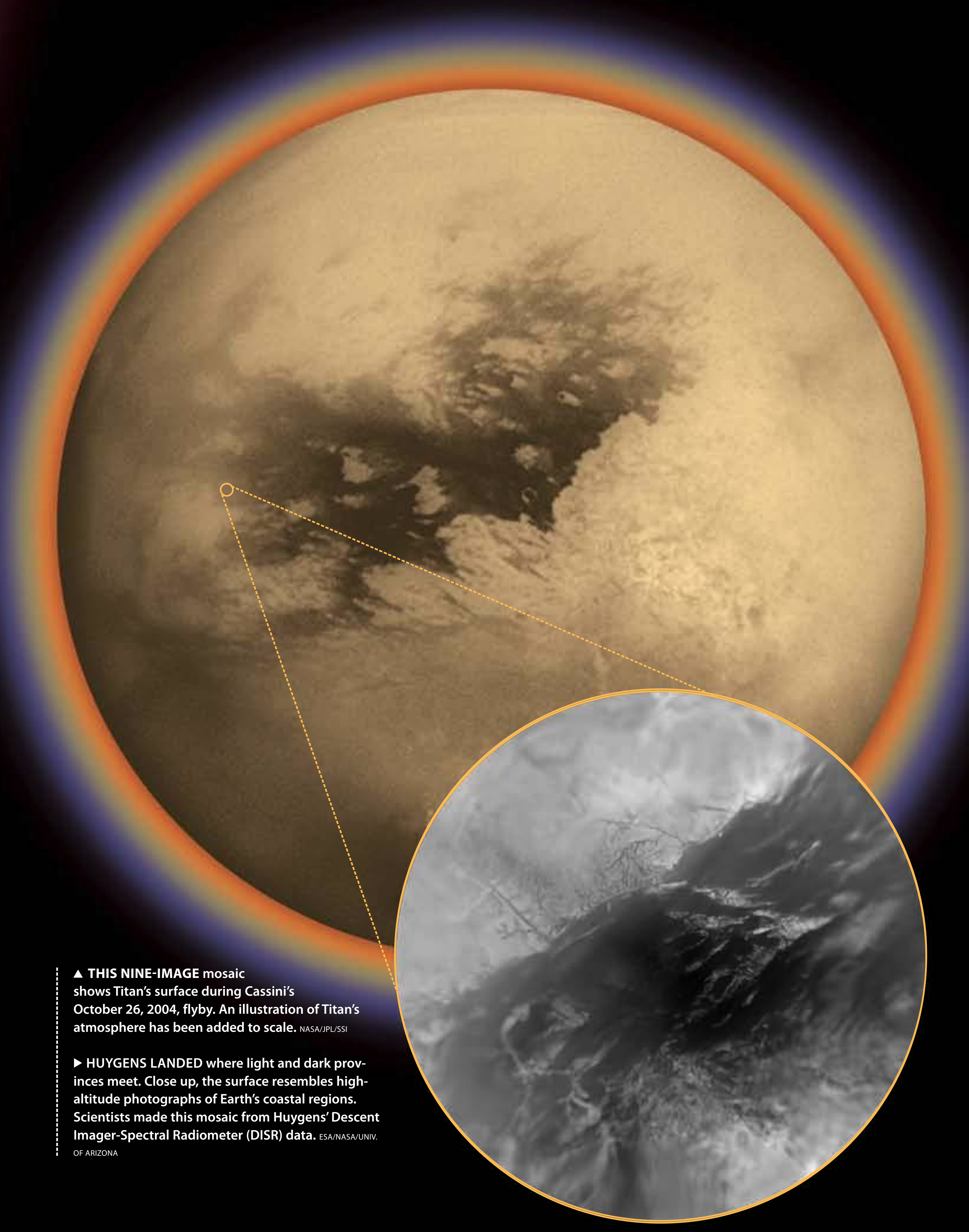
The ringed planet's largest moon has methane rivers and possible volcanoes that spew ammonia-ice lava — could life be next? /// **BY BASHAR RIZK**

On January 14, 2005, the European Space Agency's Huygens probe reached the culmination of its 7-year, 3-billion-mile journey on the Cassini spacecraft mission to Saturn. That's when Huygens slipped into the atmosphere of Titan, the largest — and perhaps strangest — of Saturn's satellites.

"Titan is undeniably the body fantastic in the Saturn system," says Carolyn Porco, leader of the Cassini imaging team. "It is the largest unexplored terrain we have left in our solar system. In my mind, it's the last great mystery." Thousands of scientists and engineers waited for the results along with millions of space enthusiasts.

Why such fascination with this haze-shrouded world, where the surface remains a mind-numbing –280° Fahrenheit (–173° Celsius)? Scientists have long seen Titan as an oddball in

***BACKGROUND*: A THIN SUNLIT** crescent of Titan contrasts with a dozen distinct haze layers extending several hundred miles above the moon's surface. The number of haze layers surprised scientists. The outer fringes of Titan's atmosphere extend nearly 400 miles (600 kilometers) into space — 10 times higher than Earth's atmosphere. NASA/JPL/SSI



▲ **THIS NINE-IMAGE** mosaic shows Titan's surface during Cassini's October 26, 2004, flyby. An illustration of Titan's atmosphere has been added to scale. NASA/JPL/SSI

▶ **HUYGENS LANDED** where light and dark provinces meet. Close up, the surface resembles high-altitude photographs of Earth's coastal regions. Scientists made this mosaic from Huygens' Descent Imager-Spectral Radiometer (DISR) data. ESA/NASA/UNIV. OF ARIZONA the solar system, and many expected Huygens would show Titan to be one of the solar system's strangest places.

They turned out to be right. Titan reminds us of Earth, which is perhaps the solar system's weirdest world. It sounds strange, but no other place reflects what we see on our home planet as well as Titan — a horribly cold and inaccessible ball of ice and rock.

Titan has a thick, mostly nitrogen atmosphere, and its main active constituent — methane — easily slips between liquid, gas, and solid phases at Titan's surface temperature. In this sense, the methane behaves similar to water on Earth.

Scientists discovered methane on the moon in the 1940s. Since then, understanding Titan has meant understanding the role methane plays in the atmosphere and on the surface. Most tantalizing of all is the association between methane and life.

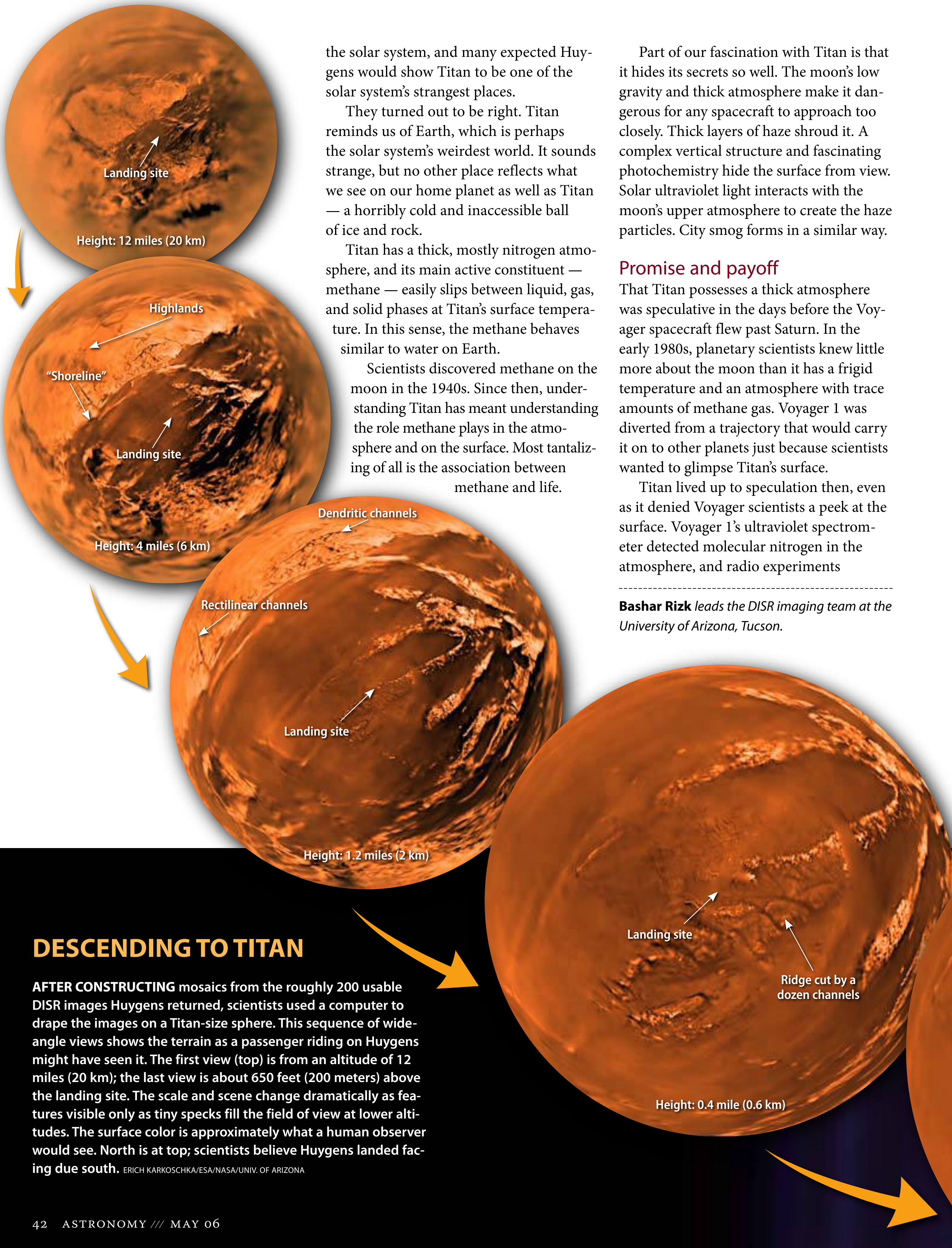
Part of our fascination with Titan is that it hides its secrets so well. The moon's low gravity and thick atmosphere make it dangerous for any spacecraft to approach too closely. Thick layers of haze shroud it. A complex vertical structure and fascinating photochemistry hide the surface from view. Solar ultraviolet light interacts with the moon's upper atmosphere to create the haze particles. City smog forms in a similar way.

Promise and payoff

That Titan possesses a thick atmosphere was speculative in the days before the Voyager spacecraft flew past Saturn. In the early 1980s, planetary scientists knew little more about the moon than it has a frigid temperature and an atmosphere with trace amounts of methane gas. Voyager 1 was diverted from a trajectory that would carry it on to other planets just because scientists wanted to glimpse Titan's surface.

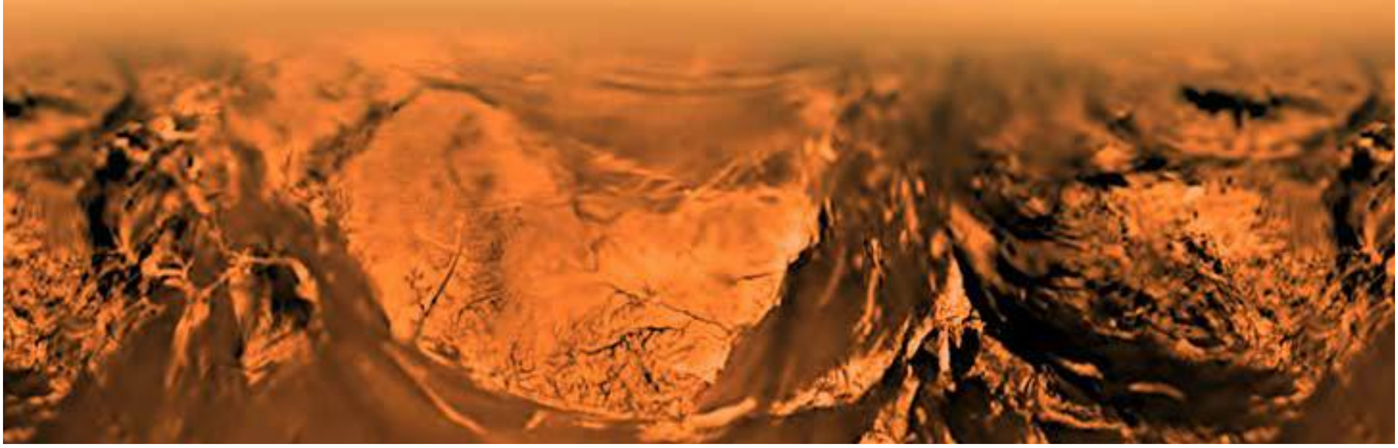
Titan lived up to speculation then, even as it denied Voyager scientists a peek at the surface. Voyager 1's ultraviolet spectrometer detected molecular nitrogen in the atmosphere, and radio experiments

Bashar Rizk *leads the DISR imaging team at the University of Arizona, Tucson.*



DESCENDING TO TITAN

AFTER CONSTRUCTING mosaics from the roughly 200 usable DISR images Huygens returned, scientists used a computer to drape the images on a Titan-size sphere. This sequence of wide-angle views shows the terrain as a passenger riding on Huygens might have seen it. The first view (top) is from an altitude of 12 miles (20 km); the last view is about 650 feet (200 meters) above the landing site. The scale and scene change dramatically as features visible only as tiny specks fill the field of view at lower altitudes. The surface color is approximately what a human observer would see. North is at top; scientists believe Huygens landed facing due south. ERICH KARKOSCHKA/ESA/NASA/UNIV. OF ARIZONA



TITAN'S BRIGHT highlands recede into the haze in this Huygens panorama from 9 miles (15 km) up. ERICH KARKOSCHKA/ESA/NASA/UNIV. OF ARIZONA

measured the atmosphere's surface pressure at 1.5 times that of Earth's. Voyager discovered a thick nitrogen atmosphere on this cold and distant outpost. There's only one other place in the solar system that has such an atmosphere: Earth.

Expectations moved to a new level after Voyager 1. Scientists suggested oceans of methane and ethane might be the source of methane in Titan's atmosphere. There must be a source that replenishes Titan's methane because sunlight breaks up the molecule.

Many looked to Titan's smoggy atmosphere as a laboratory for pre-biotic chemistry — a time capsule for studying reactions that may have taken place on the early Earth. And, while Titan was an unlikely abode for life, scientists couldn't rule out the possibility.

In short, planetary scientists viewed the moon as an exciting place to go, and the Cassini/Huygens mission was born.

Without the anticipation of a considerable scientific payoff, Cassini/Huygens would never have survived NASA's budget cuts of the 1980s. The mission was a magnificent long shot: More than 1,000 engineers, scientists, and administrators from more than 30 countries worked together to build and send something the size of a small bus 3 billion miles (4.8 billion kilometers). Even radio signals, moving at the speed of light, take 3 hours to travel round-trip.

In 1990, as Cassini and Huygens moved forward, a new era of Titan observation dawned with the launch of the Hubble Space Telescope and developments in ground-based telescopes, such as adaptive optics.

Peering into the tiny disk at infrared wavelengths, and mapping the surface by bouncing radio waves off it, revealed seemingly permanent, continent-like features surrounded by equally fixed dark regions. Scientists wondered if these darker areas were bodies of liquid. Did Titan have just the right chemistry and sources of energy to support liquids on its surface? If so, once again, Titan and Earth seemed to be the solar system's odd couple.

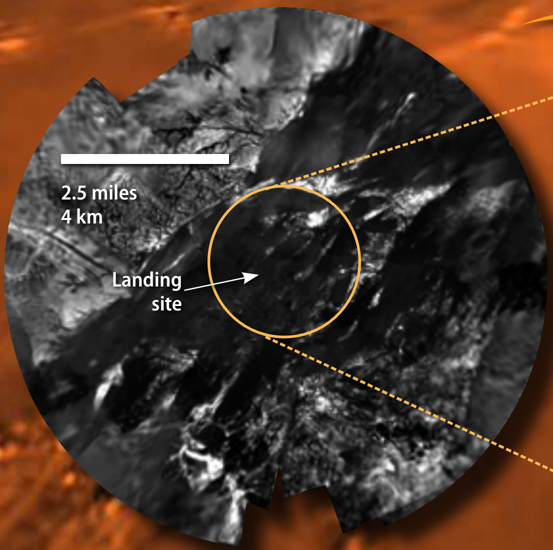
In June 2004, Cassini arrived at Saturn and recorded data in successive flybys. Titan responded predictably — haze prevented the probe's Imaging Science Subsystem (ISS), Cassini's highest-resolution instrument, from resolving any surface features smaller than a mile or so wide.

The Visual and Infrared Mapping Spectrometer (VIMS) and Radio Detection and Ranging (RADAR) instruments provided more clues by penetrating the haze at longer wavelengths. They gave intriguing glimpses of a surface that certainly does not look as though impact cratering is the dominant geological process.

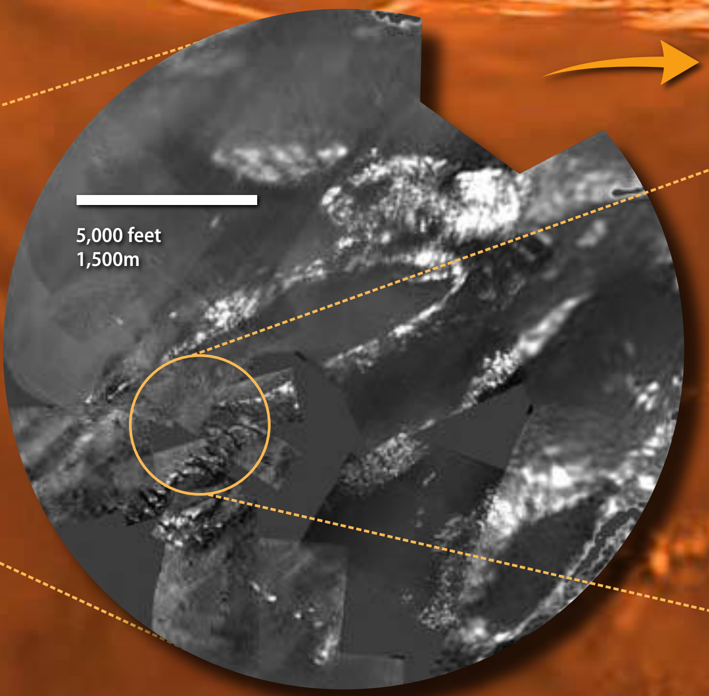
On January 14, 2005, Huygens dove into Titan's atmosphere. Given the harsh environment in which the Descent Imager-Spectral Radiometer (DISR) would operate, engineers opted against the instrument having a physical shutter — a moving part that could be easily damaged. Instead, they chose to use half of the imaging detector as an electronic shutter. This decision also reduced

Landing site
Height: 0.12 mile (0.2 km)

IT SOUNDS STRANGE, but no other place reflects what we see on our home planet as well as Titan — a horribly cold and inaccessible ball of ice and rock.



DISR IMAGES from altitudes between 10.5 and 5 miles (17 and 8 km) were assembled to produce this mosaic. Dark, narrow, linear markings, interpreted as channels, cut through the brighter terrain. The complex channel network implies precipitation — likely as methane rain — and possibly springs. ESA/NASA/UNIV. OF ARIZONA



HUYGENS IMAGES taken between altitudes of 4.3 and 0.3 miles (7 and 0.5 km) were compiled in this mosaic. ESA/NASA/UNIV. OF ARIZONA

the number of image pixels that could be radioed back.

DISR images covered a vertical swath 90° high and 20° to 40° wide, spanning 6° from straight down to 6° above the horizon. Each image contains barely 100,000 pixels, a fraction of the resolution now available in even cheap digital cameras.

Point and shoot

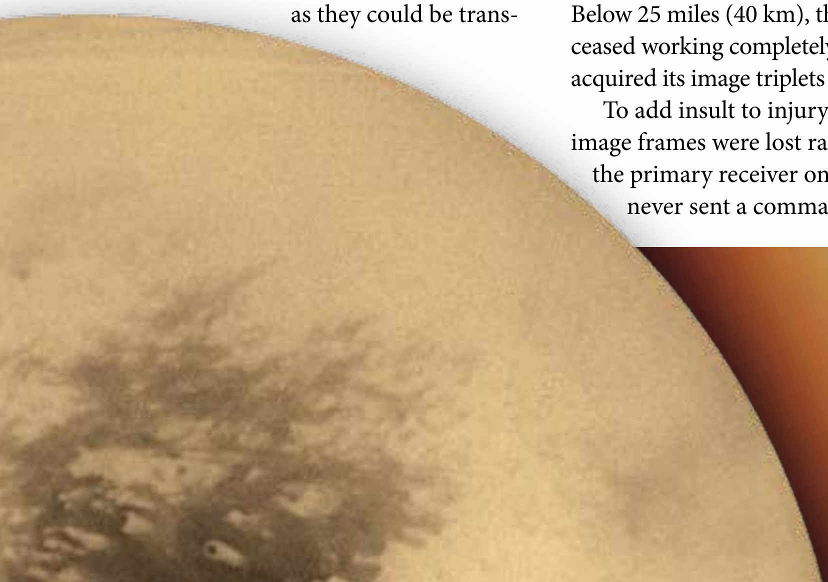
DISR's job was to act as a throwaway tourist camera. As Huygens descended, swaying and spinning under its parachute, DISR would simultaneously snap three-frame image sets (triplets) in groups of 12, as fast as they could be transmitted out of the memory buffer. Timed by DISR's Sun sensor, a photometer that pulsed like a heartbeat every time the Sun's disk passed through its field of view, the images would be spaced an even 30° apart. Huygens would break out from the haze layer at an altitude of 44 miles (70 km). By the time the probe touched down, DISR would have acquired at least 800 clear surface images.

That's not what happened. Due to cooler-than-expected temperatures and unexpected probe motions, the Sun sensor couldn't lock onto the Sun much of the time. DISR's heart kept skipping beats. Below 25 miles (40 km), the Sun sensor ceased working completely. As a result, DISR acquired its image triplets at random.

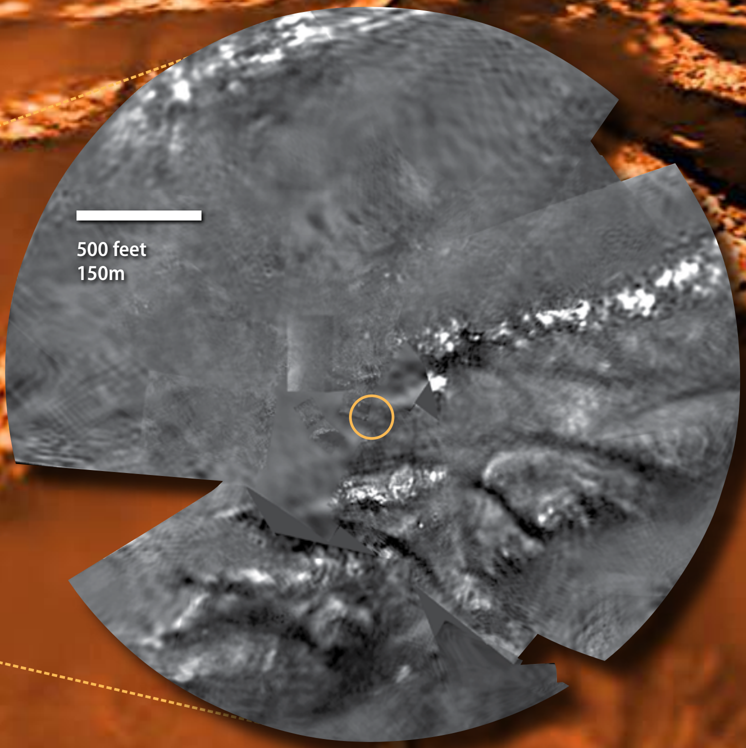
To add insult to injury, half the DISR image frames were lost randomly because the primary receiver on Cassini was never sent a command to power on. In addition, Titan's environment was not as expected. Instead of clearing out at altitudes between 19 and 44 miles (30 and 70 km), Titan's haze fills the atmosphere all the way to the surface. Instead of 800 usable images of the surface from above, DISR returned barely 200, all from within the haze.

But these 200 images show amazing stuff. A network of drainage channels has carved bright highlands that lead to an obvious shoreline adjacent to a large, dark plain. The plain is dry; we know this because Huygens landed on it. But it appears to have been flooded in the past. The plain's low contrast suggests it's uniformly covered with a single material that's different from the bright highlands.

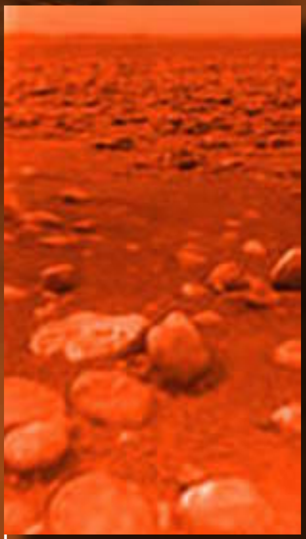
Our portrait of Titan strongly suggests the moon cycles a liquid through various phases, just as water vapor condenses as rain on Earth. Images show rounded surface rocks that appear to be sorted and



TITAN CYCLES A LIQUID through various phases, just as water vapor condenses as rain on Earth.



CHANNELS cut a ridge south of the Huygens landing site (circle). One channel appears to continue toward the craft. ESA/NASA/UNIV. OF ARIZONA


ESA/NASA/UNIV. OF ARIZONA

ICE PEBBLES at the Huygens landing site seem to be size-sorted as in a riverbed, where the smallest stones wash away.

ERICH KARKOSCHKA/ESA/NASA/UNIV. OF ARIZONA

layered according to size, positioned as though they're in a streambed within a dried-up lake. A dozen or so features imaged a few miles above the surface resemble arroyos, or water-carved gullies. Several brighter regions in higher-altitude images seem to be elongated like islands or drift deposits. And not a single obvious impact crater appears in any image. This is in marked contrast with most other solar-system bodies.

The Huygens Gas Chromatograph/Mass Spectrometer (GCMS) detected a rise in methane abundance at the surface after touchdown. Scientists believe the Huygens probe warmed liquid methane near the surface just enough to make it change into a gas.

Active geology

Long, stubby channel networks appear in the western highlands. There are also one or two round features that look like volcanic craters, and dark, circular features that suggest something upwelling from beneath the surface. Taken together, these features imply cryovolcanic flows — icy volcanism, where a mixture of ices like water and ammonia plays the role of magma on Earth. Such active geology also implies an internal energy source.

Quest for life

Surprisingly, Titan may be a suitable environment for life. Life is possible on Earth because the Sun provides a ready energy source, the atmosphere is thick, and a robust hydrological cycle ensures the creation and distribution of biochemically important substances. Life maintains Earth's atmosphere in a state that's out of equilibrium (80-percent molecular nitrogen, 20-percent molecular oxygen). Without life, Earth's atmosphere would consist mostly of carbon dioxide, like the atmospheres of Venus and Mars.

The atmosphere is an extension of the biosphere. With the exception of water, chemicals enter or exit Earth's atmosphere mostly because some species of life adds or subtracts them. The atmosphere shields life from ultraviolet radiation and cosmic rays, as well as moderates Earth's temperature through the greenhouse effect.

On Titan, we see a dense nitrogen atmosphere in tandem with a biochemically significant substance (methane) that appears to undergo intense cycling between liquid and gas phases. Only two things are lacking: a source of energy and a source of oxygen. That's enough to suggest the possibility of life to a fertile imagination. Could Titan's life be the kind that breathes its food (an aerosol haze) and eats its oxidizer (water ice)? Could organisms be recycling the aerosol haze raining down on the surface back into methane? This would explain the disequilibrium of Titan's atmosphere — a seemingly endless supply of methane gas.

No one seriously advocates this view; it's an extravagant explanation for something that can be addressed much more simply as a non-biological process, even though we can't be explicit yet about what this inanimate process might be. Life is unnecessary to explain the observations.

After all, Huygens sat on the surface for well over an hour while DISR kept taking pictures. Nothing walked or crawled or flew across the scene. If life ever began anywhere on Titan, biological principles suggest it would fill all of the planet's habitable environments. Scientists often invoke the same principles to explain why we must be alone in the cosmos.

But then again, Titan has surprised us all before.

ONLINE EXTRA Compare the chances of finding life on Mars, Europa, and Titan at www.astronomy.com/toc.

Fatal attrac

In 2029, asteroid Apophis will pass dangerously close to Earth. Depending on its exact course, it may return with a vengeance in 2036. /// BY BILL COOKE

Every evening, members of the Spaceguard Survey scan the sky for undiscovered Earth-approaching asteroids, objects that may one day impact our planet and cause global catastrophe. Although the survey is designed to spot only the big ones — the "dinosaur killers," those larger than 1,100 yards across — it occasionally detects objects a few hundred feet wide.

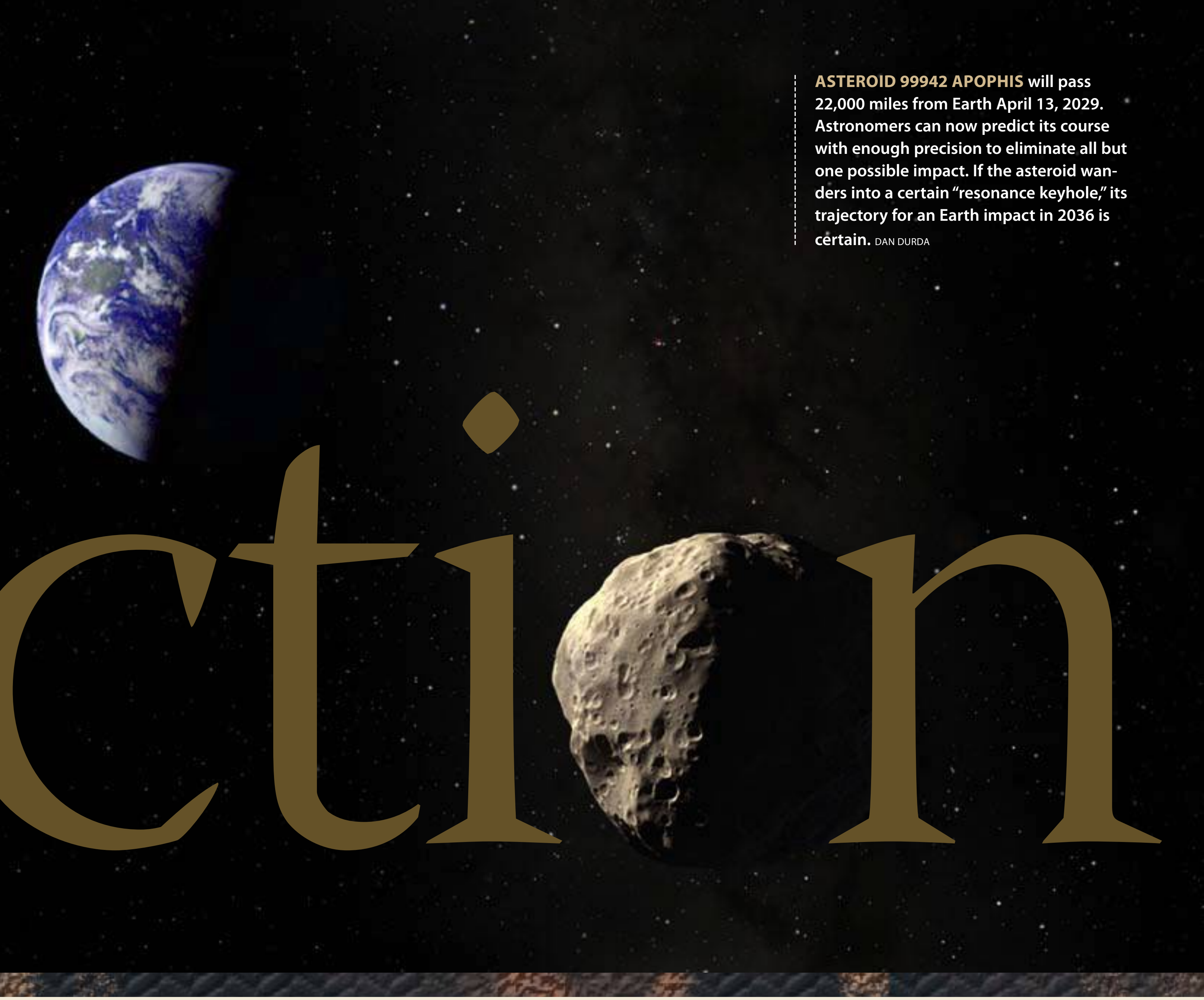
One of these mega-boulders, a few hundred yards wide, may threaten Earth 30 years from now. Its name is Apophis.

More numerous than their larger cousins, these smaller bodies still pose a risk to life. They're big enough to penetrate Earth's atmosphere and possess more striking power than hundreds of megatons of TNT. They can lay waste to large metropolitan areas or cause tsunamis. In 1908, such a football-field-size rock devastated 800 square miles (2,100 square kilometers) of Siberian tundra near the Tunguska River. As it turns out, such an object is a rather common near-Earth object (NEO).

Attitude adjustment

Calculations show we should expect something like the 1908 Tunguska event every few centuries. But until recently, Spaceguard Survey astronomers tended to regard their search as academic: Find the NEOs, precisely calculate their orbits, and determine which ones might pose threats to Earth in the next few centuries. They thought little about the actions needed against an impactor that might strike within a couple of decades — or, even worse, in a few years or months.

Bill Cooke *is an astronomer with NASA's Marshall Space Flight Center in Huntsville, Alabama.*



ASTEROID 99942 APOPHIS will pass 22,000 miles from Earth April 13, 2029. Astronomers can now predict its course with enough precision to eliminate all but one possible impact. If the asteroid wanders into a certain "resonance keyhole," its trajectory for an Earth impact in 2036 is certain. DAN DURDA

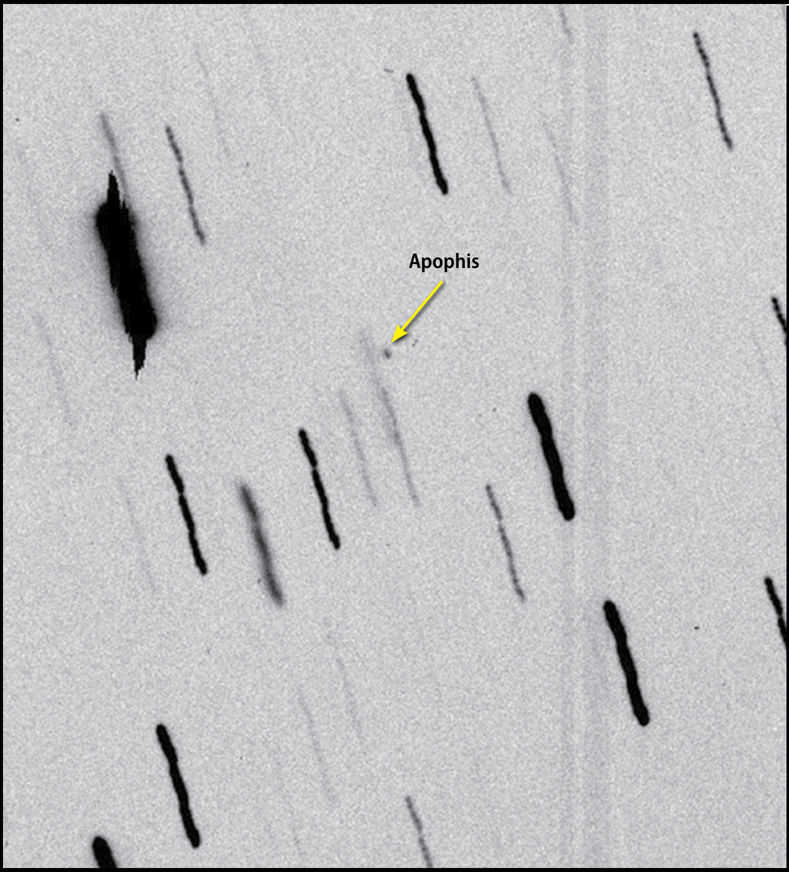
Two events in 2004 shattered the notion that searching would be enough and forced researchers to think beyond the discovery of a rock on a collision course.

On January 14, on the eve of President Bush's Vision for Space Exploration announcement, initial observations of an asteroid named AL00667 indicated it had about a 25-percent chance of hitting Earth within 36 hours. Fortunately, further observations — made by an amateur astronomer that same night — ruled out a hit. But the situation prompted the first serious discussion among asteroid-hunters about who should be warned of an impending impact.

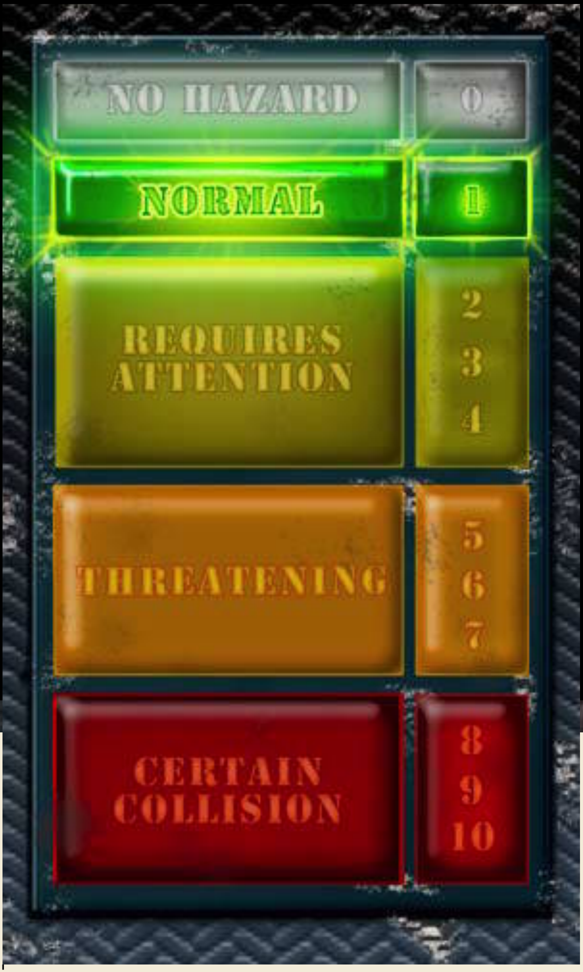
Although AL00667 missed us by more than a million miles, the incident led to the creation of an NEO "phone tree." The head of NASA's NEO Program Office at the Jet Propulsion Laboratory in Pasadena, California, will now brief a member of NASA Headquarters in Washington on any potentially threatening object; this official will then decide if the situation warrants warning other government agencies, such as the Department of Homeland Security. The AL00667 incident also fostered improvements in orbit-determination and risk-assessment software, and renewed interest in following the Spaceguard Survey with a project geared to detect objects as small as 500 feet (150 meters) across.

The second big asteroid event in 2004 occurred June 19. That's when astronomers Roy Tucker, David Tholen, and Fabrizio Bernardi, observing from Kitt Peak National Observatory in Arizona, discovered a minor planet initially designated 2004 MN$_4$ and later named Apophis. They imaged the object for only 2 nights, which didn't allow an accurate determination of its orbit.

Then, December 18, Gordon Garradd of the Siding Spring Observatory in New South Wales, Australia,



APOPHIS appears as a gray dot in this discovery image, which was taken with the 2.29m Bok Telescope at Arizona's Kitt Peak National Observatory June 19, 2004. Six months later, the space rock's climbing impact risk commanded attention from scientists studying near-Earth objects. IMAGE COURTESY D. J. THOLEN



A RICHTER SCALE for asteroid threats, the Torino scale ranks potential impacts by looking at both the risk of a strike and its explosive power. *ASTRONOMY*: JAY SMITH

rediscovered the rock. His observations, along with others made in the following days, enabled the risk-assessment software at NASA's NEO Program Office and at the University of Pisa in Italy to compute the odds of an impact. There was a 1-in-300 chance the asteroid would strike Earth April 13, 2029.

Rude awakening

More observations filtered in. On December 24, the chance of an impact jumped to 1 in 60. Then, on Christmas Day, it rose to 1 in 42. It reached a maximum of 1 in 37 December 27. This trend is unusual. For nearly all NEOs — including AL00667 in January 2004 — the odds of an impact decrease as more observations contribute to the analysis.

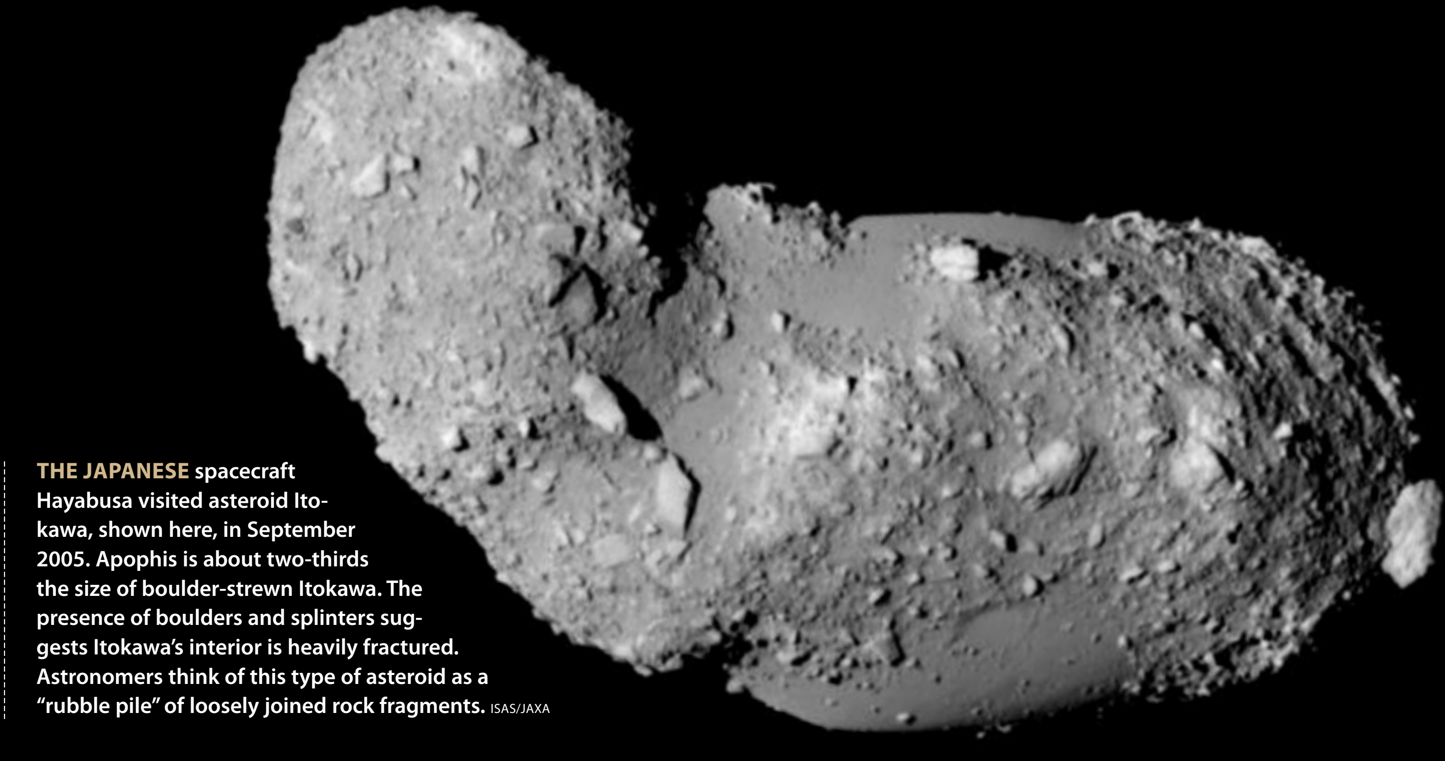
Relatively few observations determine an asteroid's initial orbit, which creates a large uncertainty in the object's future position. Add more observations spread over a longer period, and the uncertainty in the object's projected position — what astronomers call its error ellipse — gets smaller. As the error ellipse tightens, it usually shrinks to the point that Earth lies outside of it.

In short, more observations equal a better-determined orbit. This equals less uncertainty in an asteroid's future position, and usually results in an impact risk that goes to zero. Apophis bucked the trend.

If there was a bright spot in the events of that December, it involved estimates of the asteroid's size, which started out at 550 yards (500m). Size estimates decreased as the impact probability rose. Astronomers now think Apophis measures about 350 yards (320m) across. Despite its smaller size, a collision would still pack a wallop: The asteroid has the striking power of 870 megatons of TNT.

In 1961, the Soviet Union set off a nuclear weapon with the explosive power of 58 megatons of TNT — the most powerful ever detonated. A collision with Apophis would release the energy equivalent of 15 of these bombs exploding all at once. It's also between 2 and 4 times the energy released when Krakatoa, a volcano in Indonesia's Sunda Straits, blew its top in 1883. The blast and its after-

{ Apophis will pass so close to Earth that our planet's gravity will not only alter its orbit, it will also cause enormous tidal strain on the asteroid. }



THE JAPANESE spacecraft Hayabusa visited asteroid Itokawa, shown here, in September 2005. Apophis is about two-thirds the size of boulder-strewn Itokawa. The presence of boulders and splinters suggests Itokawa's interior is heavily fractured. Astronomers think of this type of asteroid as a "rubble pile" of loosely joined rock fragments. ISAS/JAXA

effects killed more than 36,000 people, mostly by tsunamis, which swept away 165 coastal villages.

Scaling risk

Astronomers have developed a means of evaluating the threat posed by a given asteroid based on the chance of an impact and its striking power. Similar to the Richter scale used to measure earthquakes, the Torino scale ranks an asteroid's impact threat from 0 (no worries) to 10 (end of civilization). Most potentially hazardous asteroids reach a value of 1 before dropping down to 0. Only a few have reached a ranking of 2 on the Torino scale. But, on Christmas Day 2004, Apophis had an unprecedented ranking of 4 — defined as a close encounter that merits attention by astronomers. No other NEO has ever posed this great a threat to Earth.

The same day astronomers announced an impact risk of 1 in 37, a search for pre-discovery images of the asteroid yielded more data, which refined the orbit. New calculations based on the expanded set of observations, now spanning 287 days, dropped Apophis' strike risk to below 1 in 10,000 — and a value of 1 on the Torino scale.

But Apophis would miss Earth by a scant 40,000 miles (64,000 km). A pass this close by a body this large is a rare occurrence, happening only once every 1,300 years or so. To an observer in Europe, Apophis would appear as a 3rd-magnitude "star" moving though the constellation Cancer at a rate of about 42° per hour. Observers with large telescopes may be able to see the asteroid's shape, provided their instruments can slew fast enough.

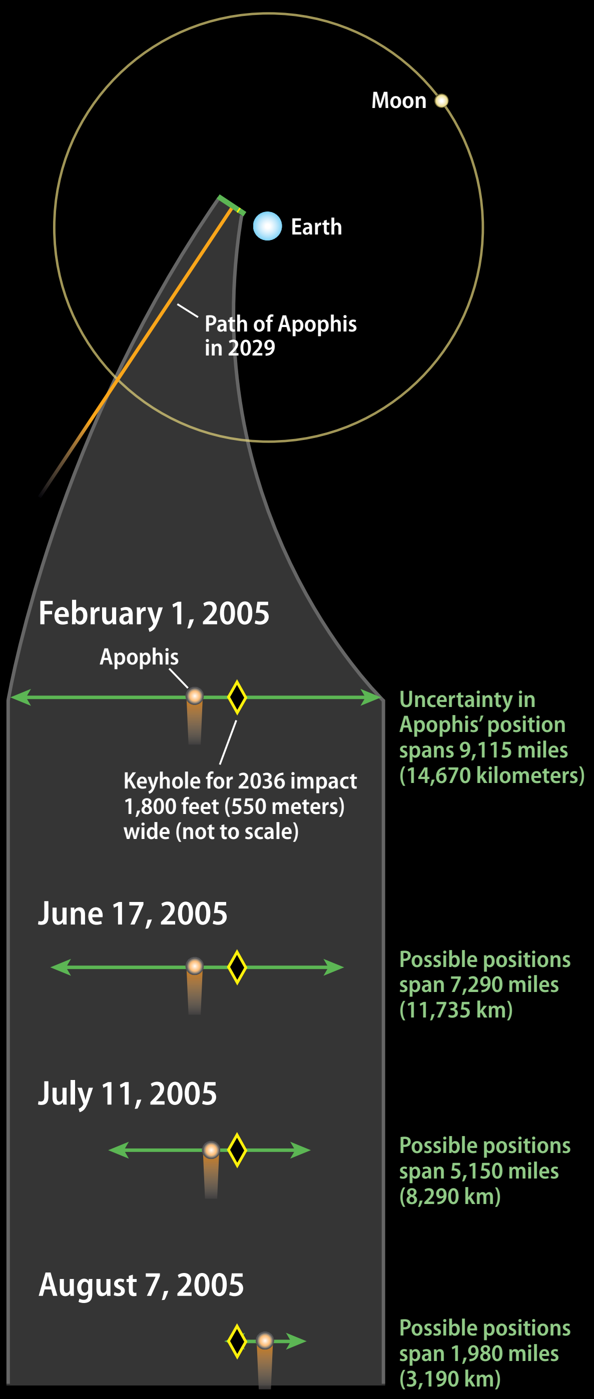
Through the keyhole

Astronomers expected Apophis' impact risk would drop to 0 once an opportunity arose to ping the object with radar. By bouncing radio waves off an asteroid, astronomers receive precise information about the rock's position and speed. The result is an orbit with far greater accuracy than can be achieved using optical telescopes.

Between January 27 and 30, 2005, a team led by Lance Benner of the Jet Propulsion Laboratory observed Apophis with the highly sensitive Arecibo radio telescope in Puerto Rico. Astronomers were in for a surprise. Yes, the asteroid would still miss Earth in 2029, but the refined orbit brings it within 22,000 miles (34,400 km) of Earth — much closer than previous estimates.

It wasn't the closer pass that concerned researchers. What bothered them was that the new position lay outside the error ellipse. This region is supposed to contain the asteroid's most likely future positions, and refining the orbit then shrinks the ellipse. But not for

Apophis and the keyhole


Moon
Earth
Path of Apophis in 2029
February 1, 2005
Apophis
Uncertainty in Apophis' position spans 9,115 miles (14,670 kilometers)
Keyhole for 2036 impact 1,800 feet (550 meters) wide (not to scale)
June 17, 2005
Possible positions span 7,290 miles (11,735 km)
July 11, 2005
Possible positions span 5,150 miles (8,290 km)
August 7, 2005
Possible positions span 1,980 miles (3,190 km)

PINNING DOWN Apophis' orbit narrowed its range of possible future positions at its 2029 closest approach. Now, astronomers can rule out a passage anywhere outside a 2,000-mile (3,200 km) span that includes only one resonance keyhole. Passing through this keyhole will place Apophis on course for a 2036 collision with Earth. *ASTRONOMY*: ROEN KELLY, AFTER PAUL CHODAS

Apophis. The asteroid had presented the scientists with yet another improbability.

Moreover, the rock's ranking on the Torino scale failed to drop to 0. Astronomers could not rule out the possibility that the asteroid might pass through one of several small regions of space called resonance keyholes. Passing through a keyhole would alter the asteroid's course just enough to cause a collision with Earth sometime in the 2030s.

As of this writing, additional observations have ruled out a passage through all but one keyhole. Not surprisingly, the remaining keyhole is the one closest to Apophis' projected path. Located about 18,700 miles (30,100 km) above Earth's surface, this 7/6 resonance keyhole — the numbers mean the asteroid would make exactly 6 complete orbits around the Sun in 7 years — is pretty small, only about 600 yards (550m) wide. But if the asteroid passes though this zone, it will be on a trajectory to strike Earth in April 2036, possibly off the western coast of northern Mexico.

Although the odds of this are slim (about 1 in 5,000, according to the latest numbers), some researchers are concerned enough to suggest that NASA send a spacecraft to the asteroid in advance of its 2029 close pass in order to plant a transponder on it. They argue that ground-based measurements aren't precise enough to tell us whether the asteroid will pass through the keyhole.

But others point out there's a 95-percent chance continued optical and radar monitoring could eliminate the keyhole passage by 2013. That leaves plenty of time to plant a transponder and, if necessary, deflect the asteroid.

Asteroid seismology

Planetary scientists would learn much from a mission to the asteroid. We've already seen incredible images from spacecraft like NASA's NEAR/Shoemaker, which visited the large main-belt asteroid Eros in 2000, and Japan's Hayabusa, the mission to Itokawa, a possible relative of Apophis. These missions returned enormous quantities of data about each asteroid's surface. Measurements of the asteroids' feeble gravity give scientists some idea of the rocks' bulk density and internal structure. But Apophis' near miss in 2029 offers an unparalleled chance to probe an asteroid.

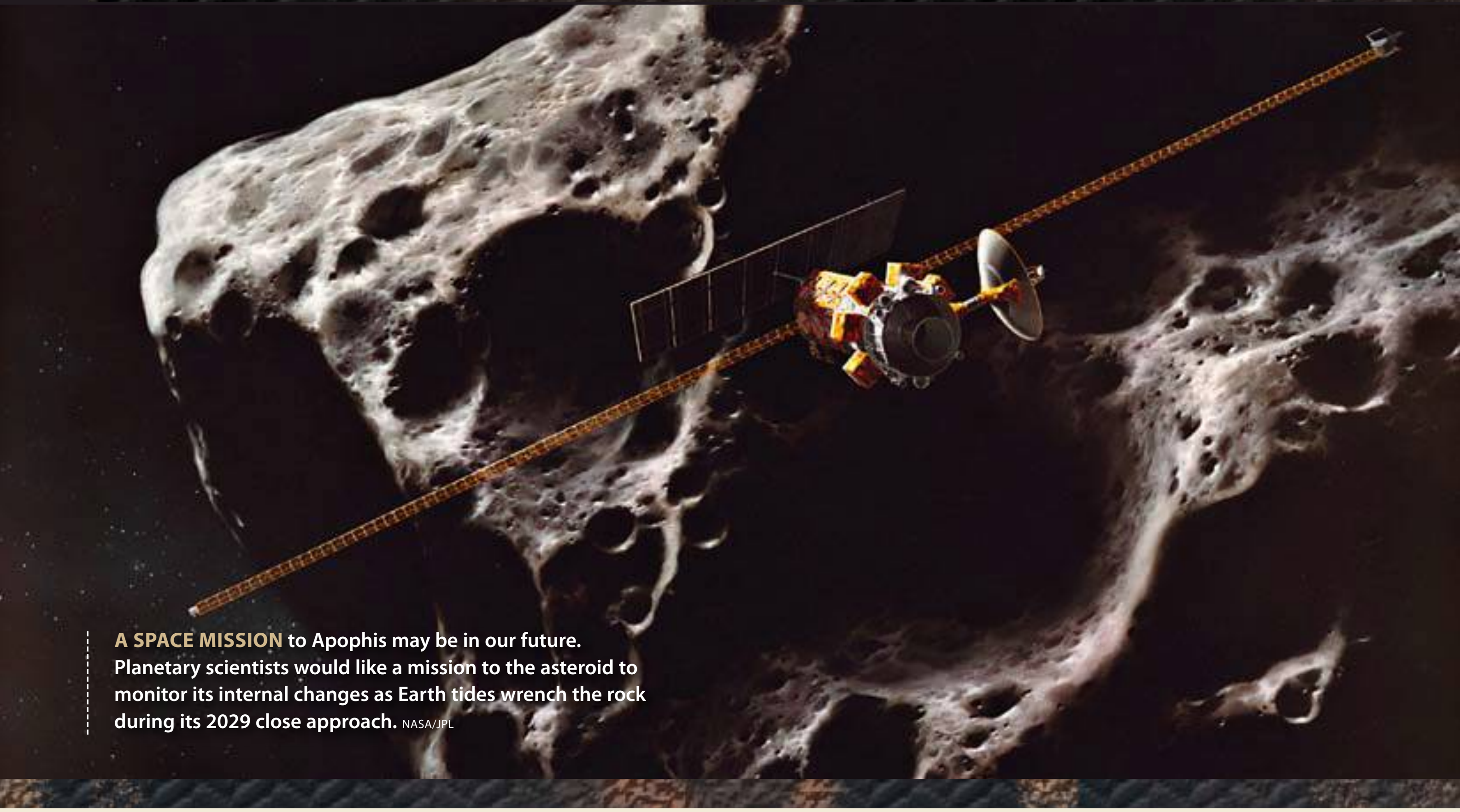
Apophis will pass so close to Earth that our planet's gravity will strain the asteroid. A team led by Daniel Scheeres of the University of Michigan calculates the Earth tides Apophis will experience could alter the rock's spin, lengthening its present 30-hour "day" by as much as 27 hours. A speed-up is also possible. Tidal stress will cause "asteroid quakes" on Apophis' surface and interior.

Put more simply, Apophis will "creak and groan" from Earth's tidal pull. A seismograph placed on the surface would return a wealth of detailed information on Apophis' internal structure. Apophis' 2029 encounter with Earth presents scientists with a "once in 1,000 years" opportunity to study an NEO comprehensively.

Meet the Lord of Chaos

Astronomers follow certain conventions when it comes to naming celestial objects. For example, Jupiter's moons are

{ Apophis' 2029 encounter with Earth presents scientists with a "once in 1,000 years" opportunity to study an NEO comprehensively. }



A SPACE MISSION to Apophis may be in our future. Planetary scientists would like a mission to the asteroid to monitor its internal changes as Earth tides wrench the rock during its 2029 close approach. NASA/JPL

named for the lovers of mythological Jupiter, Saturn's moons are named for Titans, and comets take the names of their discoverers.

Asteroid Apophis currently approaches us from inside Earth's orbit; it comes "out of the Sun," from our perspective. This makes Apophis a member of the Aten class of asteroids, which astronomers traditionally name after ancient Egyptian deities. It didn't take the discovery team long to find a suitable name from this rich pantheon.

Apophis is the Greek name for the Egyptian demon Apep, who was the enemy of light and order, the personification of evil and chaos. Depicted as a giant snake, Apophis/Apep attacked the Sun god Ra as he made his way through the Egyptian underworld during the evening hours. Solar eclipses were thought to be Apep's few daytime attempts to swallow Ra, who always succeeded in cutting his way out of the snake's belly.

However, mythology may not have been the only consideration in naming Apophis. Codiscoverers Dave Tholen and Roy Tucker are fans of the TV series *Stargate SG-1*, which for many seasons featured a persistent villain named Apophis.

"We considered a number of names, but 'Apophis' kept floating to the top," says Tucker. "Apophis was a very fitting name for 2004 MN_4 not only because of its threatening nature but also because of its evolution from an Aten asteroid to an Apollo asteroid during the 2029 encounter." Apollo asteroids approach Earth from its night side, and the 2029 encounter will change Apophis' orbit so much that it will change orbital classification.

Whatever the reasons behind Apophis' name, it's the right choice for an asteroid that has generated so much interest and debate among asteroid-hunters. It remains at a 1 on the Torino scale — stubbornly refusing to allow elimination of the risk it poses. Its 2029 close approach makes tiny keyholes in space of paramount importance, pushes our ground-tracking abilities to their limits, and forces scientists to consider placing a transponder on the asteroid's surface.

And finally, Apophis holds clues to the composition and structure of NEOs. This information is not only of scientific value. One day, knowing how these space rocks are put together may be vital in protecting our planet from the inevitable catastrophe of an asteroid strike.

On April 13, 2029, the answers to many questions about asteroids will be only 22,000 miles away. A

ONLINE EXTRA Want to know who's responsible for protecting us from asteroids? Visit www.astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

MAY 06

The bright gas-giant planets vie for attention this month, with ringed Saturn an evening standout and brilliant Jupiter on view all night.

Jupiter at its best

Ascending to his throne, the king of planets rules May nights. Jupiter rises near sunset, lies highest in the south around midnight, and sets near sunrise. Unlike the twinkling stars in the background, Jupiter shines with a steady light, brilliant at magnitude –2.5. Combined with its pale peach color, these characteristics may disguise it as a distant plane's landing light.

What a wonder to behold. Jupiter appears as its own world even through the smallest telescope. Up to four white dots flank the bright disk. These are Io, Europa, Ganymede, and Callisto — the large moons discovered by Galileo in 1610. During the course of a night, you can watch them shift position in a delicate orbital ballet.

At higher magnification, Jupiter's glaring white disk becomes more subdued. Two large purple-brown stripes oriented along the line of the moons stand out. With patience and experience, you'll see more of these huge cloud systems. If you're lucky, a black dot will transit the disk for a couple of hours — a jovian moon's shadow cast on the cloud tops. Late evening and early morning views of Jupiter are best, once the planet has climbed above the worst turbulence in Earth's lower atmosphere.

JUPITER REACHES OPPOSITION **in early May, when it shines brightest and appears biggest.** NASA/JPL/SSI

As great as Jupiter is, don't miss Saturn. The magnificent ringed planet lies halfway to the zenith in the western sky as night falls. In a couple of months, twilight will consume it. Look for two or three pinpoints nearby — Saturn's brightest moons. Because they lie about twice as far away from Earth as Jupiter's Galilean moons, Titan and Rhea appear considerably fainter.

A fragment of Comet 73P/Schwassmann-Wachmann 3 should pass within 7 million miles of Earth May 12. This likely will be the comet's last revolution around the Sun. If we're lucky, it will flare to 2nd magnitude before diffusing into space dust. Although this may sound bright, it's what we would see if all of its light were concentrated into a point. Chances are, the comet will display a diffuse halo more than twice the Moon's apparent size, which could render it invisible from the city.

Grab your binoculars and head to the country in late April or the first few nights of May. The comet will hang low in the northeast, to the right of the bright star Vega. Unfortunately, 73P's closest approach to Earth happens right when the Full Moon whitewashes the sky.

Speaking of primordial snowballs, dust from Comet Halley will burn up in Earth's atmosphere during the annual Eta Aquarid meteor shower. The shower's peak occurs Thursday night, May 4/5, when an observer under a dark sky should see a "shooting star" every few minutes.

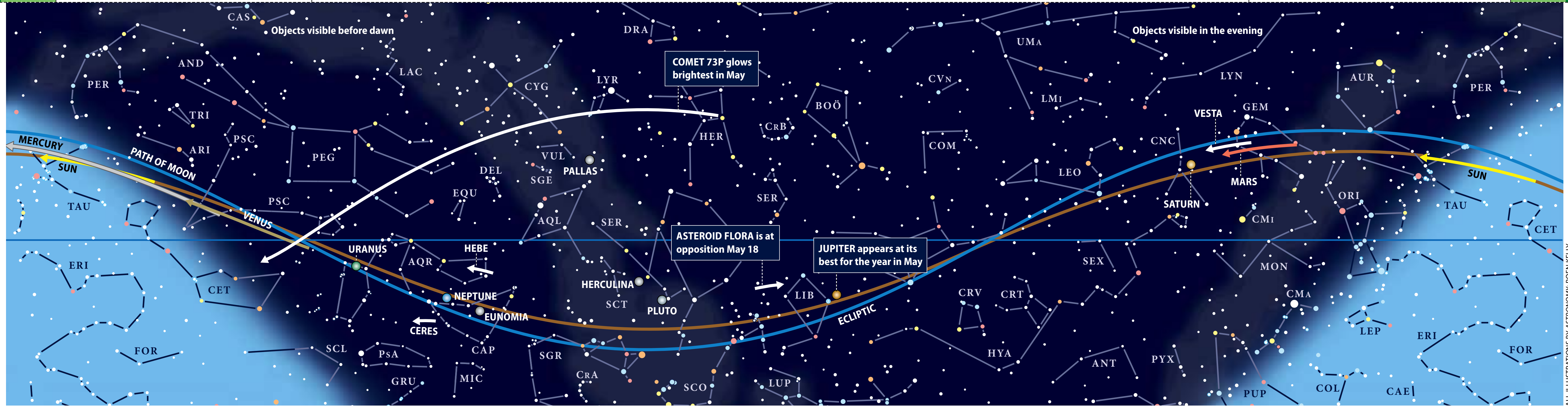
Avid skywatchers continue to follow Mars. The fading orange light hangs just left of a crescent Moon as May opens. Although Mars remains prominent to naked eyes, a telescope shows little but a rust-colored surface because the planet lies so far away. With binoculars, follow Mars as it closes in on Omega (ω) Geminorum; it grazes past the star May 7.

As the Moon waxes in early May, it sweeps above Saturn on the 3rd. At full phase, it then appears below Jupiter both May 11 and 12. A couple of weeks later, the waning crescent Moon joins blazing Venus at dawn. Venus currently lies on the opposite side of the solar system from us and shows a shrinking gibbous disk to telescope owners.

A thousand years ago this month, a star exploded in the constellation Lupus. Credible eyewitness reports tell how this "guest star" could be seen easily during daylight. It shone with the light of a half-lit Moon or more. Turn to page 57 to find out what may await us when the next supernova lights up our corner of the galaxy.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



Objects visible before dawn
Objects visible in the evening
COMET 73P glows brightest in May
ASTEROID FLORA is at opposition May 18
JUPITER appears at its best for the year in May
MERCURY
SUN
PATH OF MOON
VENUS
URANUS
HEBE
NEPTUNE
EUNOMIA
CERES
PALLAS
HERCULINA
PLUTO
ECLIPTIC
VESTA
MARS
SATURN
CAS
AND
PER
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CMI
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SCT
SCO
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LEP
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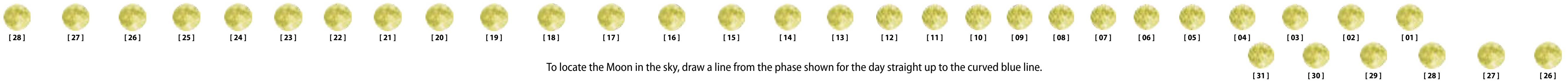
COL
CAE

ALL ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY



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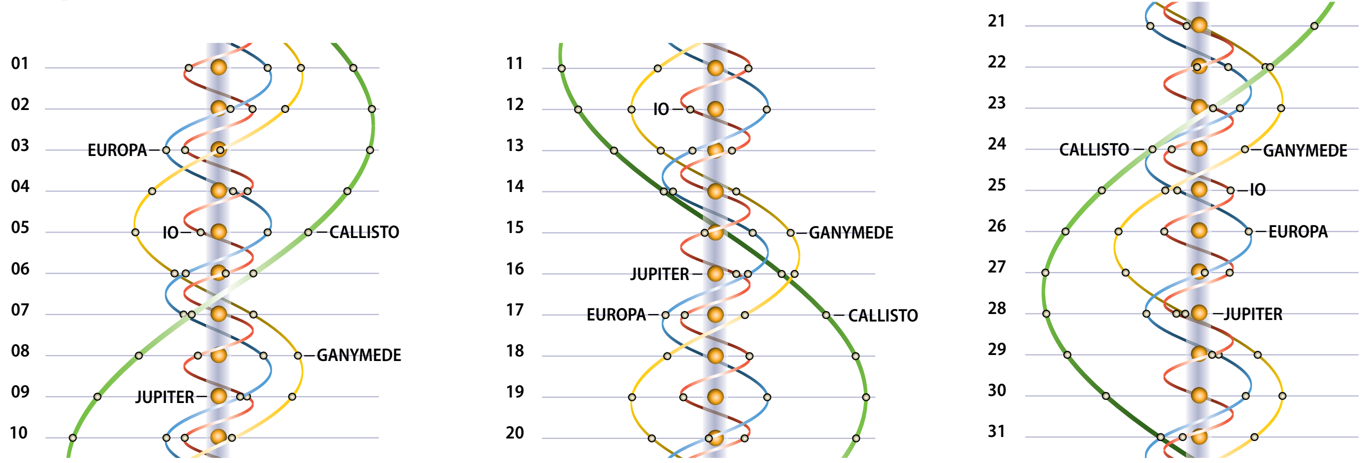
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	May 1	May 31	May 15	May 15	May 15	May 15	May 15	May 15	May 15
Magnitude	–0.6	–1.2	–3.9	1.6	–2.5	0.3	5.9	7.9	13.9
Angular size	5.6"	5.6"	15.6"	4.6"	44.6"	17.7"	3.5"	2.3"	0.1"
Illumination	80%	83%	71%	93%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.191	1.202	1.068	2.033	4.425	9.398	20.406	29.964	30.260
Distance (AU) from Sun	0.397	0.331	0.728	1.657	5.419	9.131	20.080	30.055	31.113
Right ascension (2000.0)	1h24.9m	5h30.8m	0h51.0m	7h19.2m	14h42.2m	8h32.9m	23h02.8m	21h28.7m	17h44.1m
Declination (2000.0)	6°27'	25°11'	3°31'	23°43'	–14°21'	19°35'	–6°56'	–15°05'	–15°42'

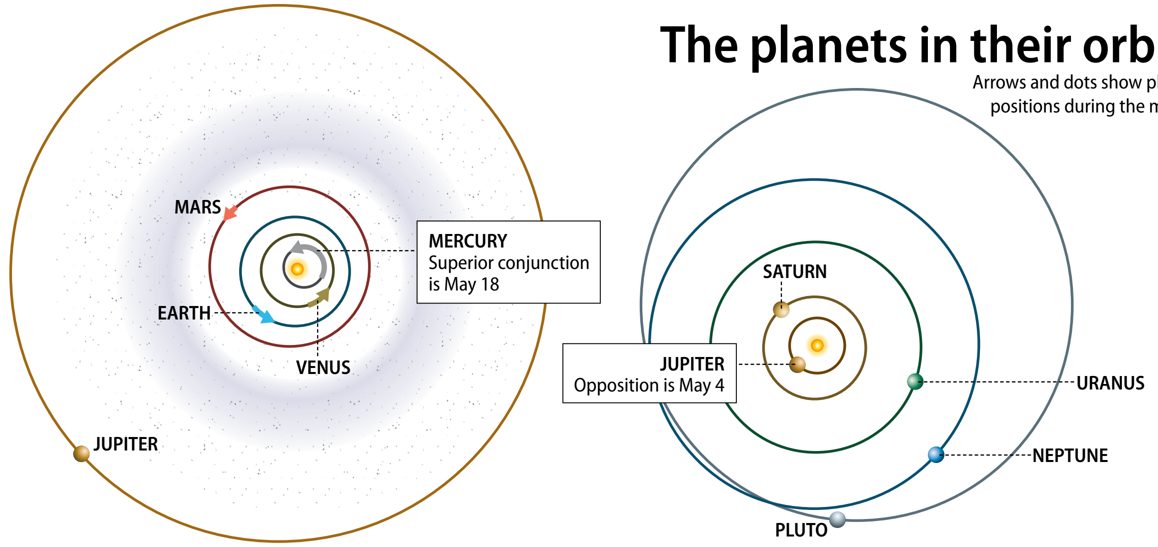
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on date shown. South is at top to match the view through a telescope.



The planets in their orbits

Arrows and dots show planets' positions during the month.



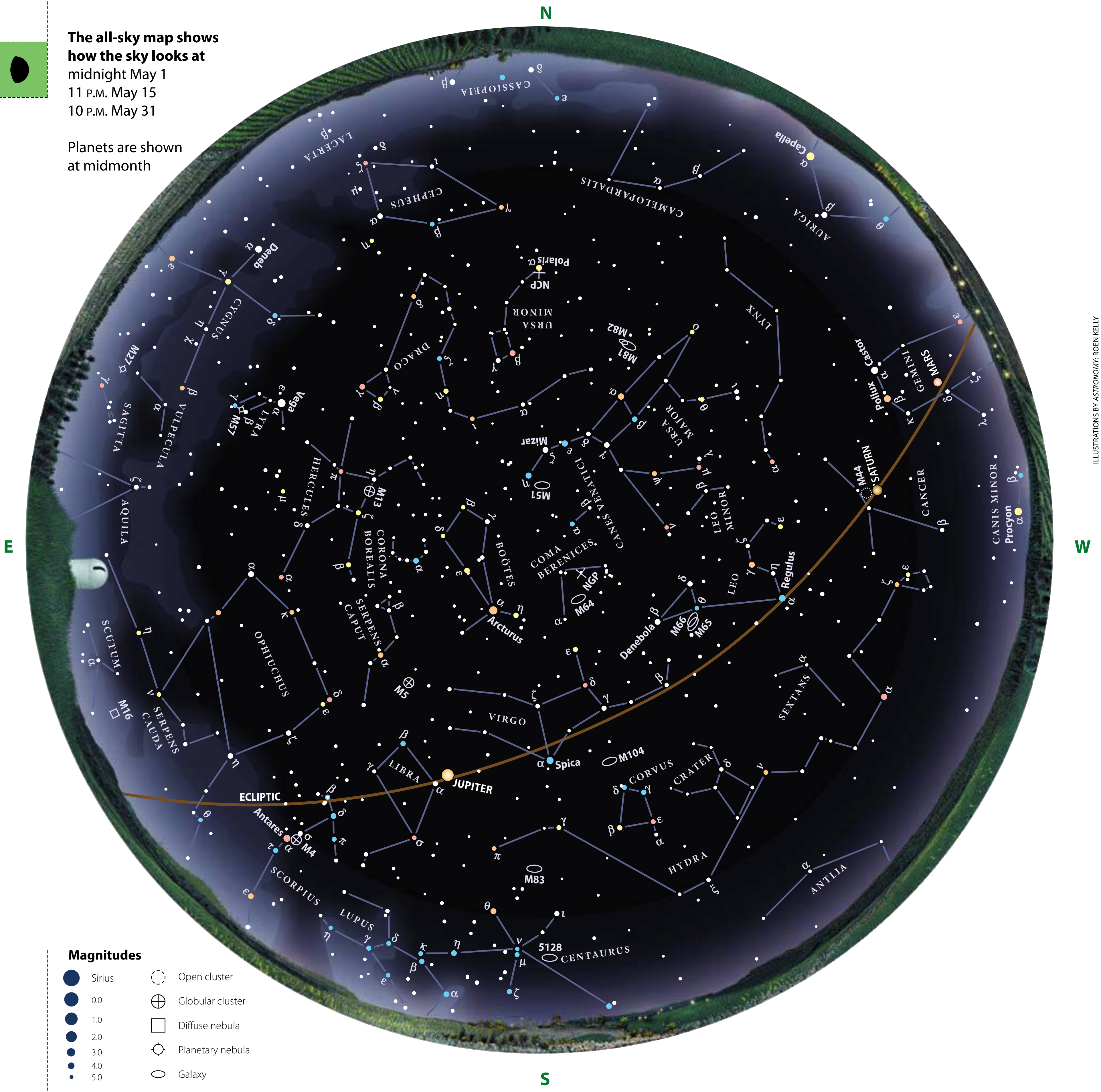
MARS
EARTH
VENUS
JUPITER
SATURN
URANUS
NEPTUNE
PLUTO

MERCURY
Superior conjunction is May 18

JUPITER
Opposition is May 4

The all-sky map shows how the sky looks at
midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown
at midmonth


N
E
S
W
CASSIOPEIA
LACERTA
CEPHEUS
CAMELOPARDALIS
Capella
AURIGA
Deneb
CYGNUS
Polaris
NCP
URSA MINOR
DRACO
M82
M81
LYNX
M27
SAGITTA
VULPECULA
Vega
LYRA
M57
Castor
Pollux
GEMINI
MARS
URSA MAJOR
Mizar
M51
CANES VENATICI
LEO MINOR
HERCULES
M13
M44
SATURN
CANCER
CANIS MINOR
Procyon
AQUILA
CORONA BOREALIS
BOÖTES
COMA BERENICES
NGP
M64
Arcturus
LEO
Regulus
SERPENS CAPUT
Denebola
M66
M65
SCUTUM
OPHIUCHUS
M5
SEXTANS
M16
SERPENS CAUDA
VIRGO
Spica
M104
CORVUS
CRATER
ECLIPTIC
LIBRA
JUPITER
Antares
M4
SCORPIUS
HYDRA
M83
ANTLIA
LUPUS
5128
CENTAURUS
Magnitudes
Sirius
0.0
1.0
2.0
3.0
4.0
5.0
Open cluster
Globular cluster
Diffuse nebula
Planetary nebula
Galaxy

This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

may 06

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
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ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

02 The Moon passes 4° north of Mars, 7 A.M. EDT

04 The Moon passes 4° north of Saturn, 5 A.M. EDT

Jupiter is at opposition, 11 A.M. EDT

05 Eta Aquarid meteor shower peaks

First Quarter Moon occurs at 1:13 A.M. EDT

07 The Moon is at apogee (251,389 miles from Earth), 2:46 A.M. EDT

10 The Moon passes 0.3° north of Spica, 8 P.M. EDT

12 The Moon passes 5° south of Jupiter, noon EDT

13 Full Moon occurs at 2:51 A.M. EDT

14 The Moon passes 0.1° south of Antares, 11 A.M. EDT

18 Mercury is in superior conjunction, 4 P.M. EDT

Asteroid Flora is at opposition, 8 P.M. EDT

19 The Moon passes 4° south of Neptune, 11 A.M. EDT

20 Last Quarter Moon occurs at 5:21 A.M. EDT

21 The Moon passes 1.0° south of Uranus, 6 A.M. EDT

22 The Moon is at perigee (229,043 miles from Earth), 11:25 A.M. EDT

24 The Moon passes 4° north of Venus, 4 A.M. EDT

27 New Moon occurs at 1:26 A.M. EDT

30 The Moon passes 3° north of Mars, 11 P.M. EDT

31 The Moon passes 4° north of Saturn, 5 P.M. EDT

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

THE DEEP SKY

It's been a millennium since the brightest supernova ever recorded. Today, we await the next stellar death while viewing the colorful scene of a Sun-like star's demise.

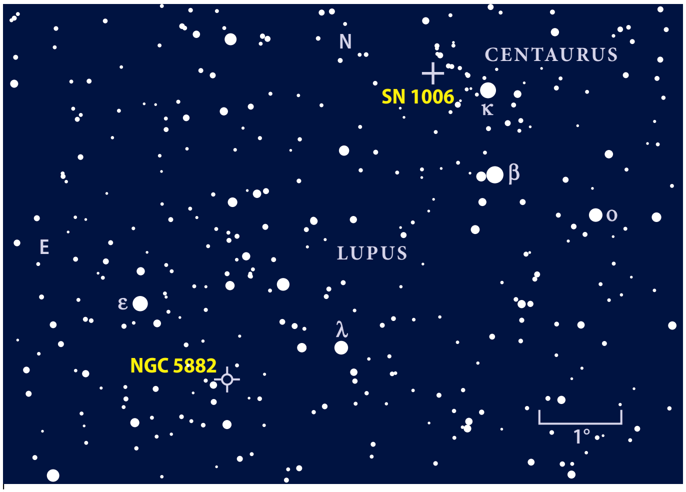
Brightest star ever seen

A thousand years ago this month, a star in the constellation Lupus the Wolf ripped itself apart in a cataclysmic explosion. The supernova peaked at an incredible brightness of around magnitude –7.5, some 15 times brighter than brilliant Venus at its best. Skywatchers easily saw it in broad daylight and followed it for more than 2 years at night. From the Northern Hemisphere, Lupus lies near the southern horizon around midnight this time of year.

The supernova appears to have been a type Ia — a white dwarf that accumulated too much matter from a companion star and then detonated. Today, when we look in the direction where the supernova shone, we don't see much. A few gaseous filaments show up in images taken with professional telescopes. Apparently, little interstellar material surrounds the explosion site, so the expanding shock wave doesn't have much gas to excite. The region glows more brightly in radio waves and X rays.

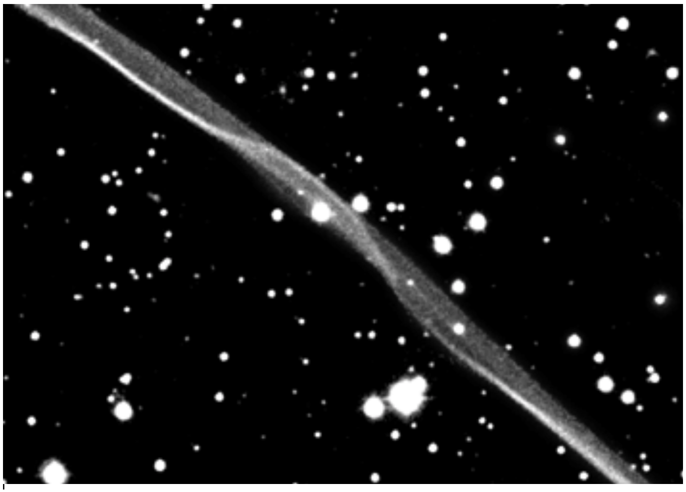
What might the next big one look like? We know the Milky Way is overdue for a supernova — they occur, on average, once a century, and the last one seen occurred more than 400 years ago. The best candidate star we know is Eta Carinae, a massive star tucked inside the brightest nebula visible from Earth. But a type Ia supernova could erupt in a currently nondescript region of sky.

A supernova gleaming at magnitude –7.5 would stun the world, even today. It would appear conspicuous in daylight. At night, its light would dazzle. Perhaps its most striking characteristic would be twinkling. Neither Venus, which peaks around magnitude –4.5, nor the brightest flares from Iridium satellites, which rival our hypothetical supernova, twinkles. Their steady glows arise because these objects appear large enough that turbulence in Earth's atmosphere smears the image. But with a point source like a supernova, every atmospheric undulation shifts the distant object's light back and forth, making it twinkle.



ASTRONOMY: ROEN KELLY

DEATH REIGNS IN LUPUS, where a star exploded 1,000 years ago and another one is taking its last gasp.



MIDDLEBURY COLLEGE/NOAO/AURA/NSF

A FEW WISPY FILAMENTS are all that remain of the star that created the brightest supernova ever seen.

A bright guest star would cast shadows and shine bright enough to make reading star charts a snap without artificial illumination. The supernova's months-long brilliance would ruin dark adaption, so deep-sky observers might have to concentrate on brighter targets.

Of course, some may interpret the supernova as a portent of doom and sign of apocalypse. However, backyard observers will be there with telescopes to share the beauty and wonder of the universe with all who venture outside and look up.

A stellar death shroud

When a massive star explodes, the conflagration can light up a whole galaxy. But for a Sun-like star, the end is more gentle. Instead of an explosion, the star puffs off its outer layers. For a few thousand years, the ejected gas glows as a beautiful planetary nebula.

One of the most colorful planetaries in the sky lies just a few degrees southeast of the site of Supernova 1006. NGC 5882 shows a distinct blue-green hue in 6-inch and larger telescopes. The planetary appears as a circular shell 15" across. A faint halo, approximately 5' in diameter, surrounds the shell, but it glows too faintly to see with backyard scopes.

THE PLANETS

May is giant-planet month: Saturn looks nice in the evening, and Jupiter reaches opposition. Throw in a fine meteor shower and some warm evenings, and you're set for some excellent viewing.

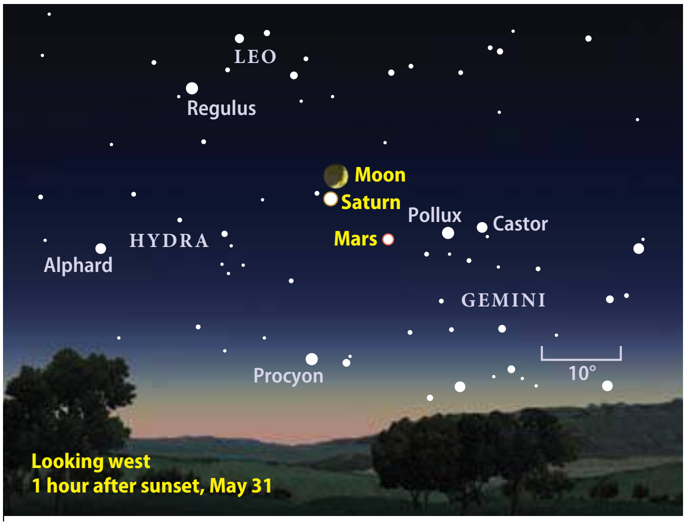
After sunset May 1, the western sky holds Mars, Saturn, and the Moon. **Mars** shines at magnitude 1.5 and lies 6° southeast of a crescent Moon and one-and-a-half Moon-widths southeast of 3rd-magnitude Epsilon (ε) Geminorum. With Mars now on the far side of the solar system from Earth, it appears just 5" across and shows little detail through a telescope. Mars traverses Gemini until the end of May, when it crosses into neighboring Cancer and lies in line with Castor and Pollux.

On May 3, the waxing crescent Moon will guide you to the next planet, **Saturn**. Both lie high in the west-southwest at the end of twilight, with Saturn 5° left of the Moon. Saturn remains on view until early morning all month.

The ringed planet crawls across the constellation Cancer the Crab and creeps closer to the Beehive star cluster (M44) for a final time this year. On May 31, it stands less than a Moon-width southwest of the cluster. The two make a fine sight in binoculars. Meanwhile, a 5-day-old crescent Moon stands watch over the pair, some 3° to the northeast.

Saturn's elegant rings span 40" and present a fine view through any telescope. Expect to see the dark gap of the Cassini Division separating the outer A ring from the brighter B ring. The planet's disk measures 18" across and shows a dark equatorial belt along with more subtle, dusky shadings.

You'll easily spy Saturn's biggest and brightest moon, Titan, lurking near the planet. It passes due north of Saturn May 8 and 24 and due south May 16. Intriguing Iapetus brightens during May as it heads toward its greatest western elongation May 29. On this late spring evening, it shines at its brightest, magnitude 10.1. The moon's dual personality — it appears significantly brighter when west of Saturn — arises because it has one bright and one dark hemisphere that reflect vastly different amounts of sunlight.



ASTRONOMY: ROEN KELLY

THE MOON JOINS Mars and Saturn for an impressive display in late May's evening sky.

NASA/JPL/SSI

TWO-FACED IAPETUS, which changes brightness as it orbits Saturn, revealed this stark contrast to the Cassini spacecraft.

Jupiter reaches opposition May 4, when it rises in the east-southeast at sunset. Jupiter tips the scales as the heaviest planet in the solar system, appropriate now that it lies in the constellation Libra the Scales. It lies near Alpha (α) Librae, or Zubenelgenubi, this month. Jupiter gleams at magnitude –2.5, outshining the star a hundredfold.

The best time to view Jupiter is near local midnight (1 A.M. local daylight time), when the giant planet stands highest above the southern horizon. A small scope at about 75x readily shows two dusky belts spanning Jupiter's equatorial region. The planet's disk measures 44.7" across at opposition. Notice its polar diameter spans 3" less, which gives Jupiter a distinct flattened appearance. This comes about because of its fast rotation — the planet's gravity can't hold the bulging equatorial regions as tightly.

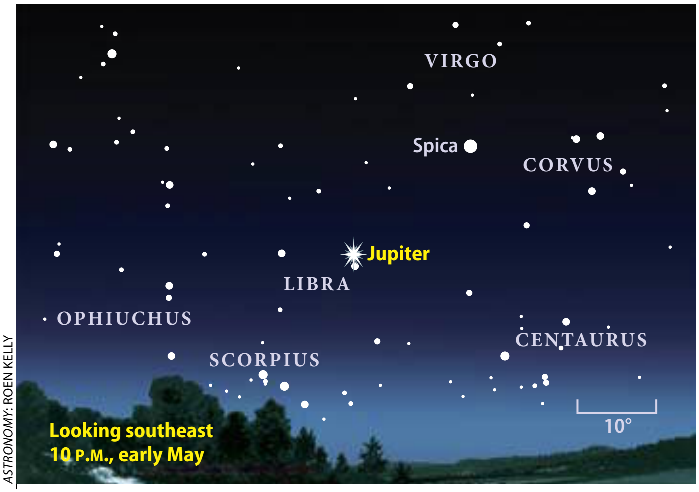
Moving in line with Jupiter's equator are the four bright Galilean moons: Io, Europa, Ganymede, and Callisto. Each moon appears as a bright "star" adjacent to Jupiter and moves relative to every other hour to hour, and night to night.

If you view the planet for only a minute, the main dusky belts may be all you see. Watch for a longer period, and your eye will attune to Jupiter's brilliant disk. More subtle features — festoons, wisps, dark and bright spots — then will come into view. These features whisk around Jupiter in a period between 9 hours and 50 minutes and 9 hours and 55 minutes. The exact rotation period depends on latitude; higher latitudes rotate slower than lower ones. Jupiter doesn't rotate as a solid object like Earth does. Along the boundaries separating different rotation speeds, dramatic turbulence results. This is what creates the fascinating patterns along the edges of its dark belts and light zones.

Let's now turn from the biggest planet to the biggest planetary challenge: spotting **Pluto**. The most distant planet glows dimly at magnitude 13.9 among the background stars of Serpens Cauda. Use the 3.5-magnitude star Xi (ξ) Serpentis as a guide or, if you're more familiar with deep-sky objects, the bright open cluster M23 in Sagittarius. Pluto lies 1.7° east of Xi and about 5° northwest of M23. Even though an 8-inch telescope can bring the dim planet into view, a 10-inch or larger scope makes direct viewing easier. You'll need an accurate star chart that shows stars down to 14th magnitude and a couple of clear nights to confirm a Pluto sighting. Sketch or image the field the first night, then return to see which faint object moved in that time, betraying its planetary identity.

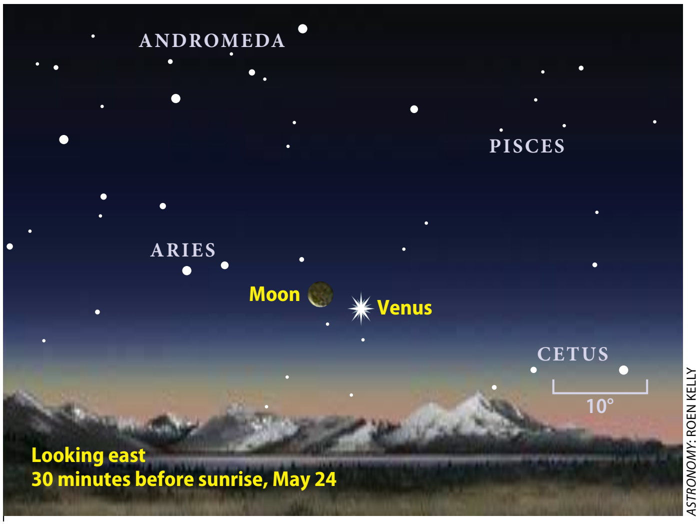
Neptune lies closer to the Sun than Pluto. Combined with its greater girth, the Sun's eighth planet glows more than 100 times brighter, at magnitude 7.9. In mid-May, binoculars will reveal Neptune by 4 A.M. local daylight time, about 2 hours after it rises. You'll find it floating in Capricornus the Sea Goat 2° northeast of Iota (ι) Capricorni. Its small disk, just 2.3" in diameter, looks distinctively non-stellar. And its blue-gray hue appears noticeable even in small scopes.

As dawn breaks, **Uranus** sits in the same binocular field as Lambda (λ) Aquarii. In early May, the planet lies nearly 15° above the east-southeastern horizon at 5 A.M. local daylight time. Look for what appears to be a double star with 6th-magnitude components — one object is the star 81 Aquarii, the other is Uranus. By the 18th, Uranus forms a nice right-angle triangle with the stars 81 and 82 Aquarii. The group then stands 25° high at 5 A.M.



ASTRONOMY: ROEN KELLY

JUPITER COMMANDS THE SKY from sunset to sunrise, as it takes its place among the stars of Libra.



ASTRONOMY: ROEN KELLY

BRILLIANT VENUS receives a visit from a waning crescent Moon the morning of May 24.

While you're trying to find Uranus, a brilliant object pokes above the eastern horizon. You don't need any optical aid to spot **Venus**, which shines at magnitude –3.9. If you view it at the same time each morning, say 5:15, Venus doesn't change altitude appreciably. The background stars shift past Venus as it moves through Pisces. In mid-May, the planet's shrinking disk measures 16" across, while its waxing phase appears 71-percent lit.

Although Venus reaches aphelion, its greatest orbital distance from the Sun, May 17, this doesn't improve the planet's visibility. The shallow angle of the ecliptic to the horizon keeps the "morning star" hugging the horizon. A waning crescent Moon passes 4° from Venus May 24 and creates a beautiful early morning spectacle.

Mercury makes a quick swing around the Sun during May. It begins the month west of the Sun and appears briefly above the eastern horizon as the dawn sky brightens. On the 1st, it shines at magnitude –0.6 and rises about 30 minutes before the Sun.

It rapidly sinks out of sight until late May, when it reappears in the evening sky. Look for it 45 minutes after sunset. On the 28th, Mercury lies 10° below a thin crescent Moon. And on the 30th, the planet lies between the two stars that mark the horns of Taurus the Bull. Mercury then shines at magnitude –1.2, so it's noticeably brighter than the stars.

Virgo's brightest star, Spica, reappears from behind the Moon's limb May 10 about 45 minutes before the Sun sets. Only observers along the United States' eastern seaboard can see this daylight event. Visit the web site of the International Occultation Timing Association (www.lunar-occultations.com/iota/iotandx.htm) for details for your specific location.

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*

METEORS AND MOONS

The year's best Southern Hemisphere meteor shower — and a fine one from mid-northern latitudes — peaks with the Moon out of the sky.

Halley's children return

Two annual meteor showers derive from dust released by Comet 1P/Halley during its countless trips through the inner solar system. The first arrives in early May. The Eta Aquarid shower remains active from April 19 through May 28, but you'll want to observe as close to the May 4/5 peak as you can. This year, the First Quarter Moon doesn't interfere with the prime viewing hours before dawn on the 5th.

The shower's radiant lies near the Water Jar asterism in the constellation Aquarius, which rises about 2 hours before twilight begins. From the Northern Hemisphere, the radiant stands nearly 20° high in the east-southeast by 4 A.M. local daylight time. (From the favored Southern Hemisphere, the radiant lies nearly 60° high.)

The number of meteors you see depends on the radiant's altitude. If it appeared overhead (the so-called zenithal hourly rate), you'd see nearly one meteor per minute. The actual, lower radiant reduces this number noticeably. Still, May's warm weather makes the Eta Aquarids among the year's best-observed showers. To see the most meteors, observe from a dark-sky site.

The second meteor shower spawned by Comet Halley arrives in October. The Orionids don't produce as many meteors as the Eta Aquarids, but the radiant climbs higher, and they benefit this year by peaking at New Moon.

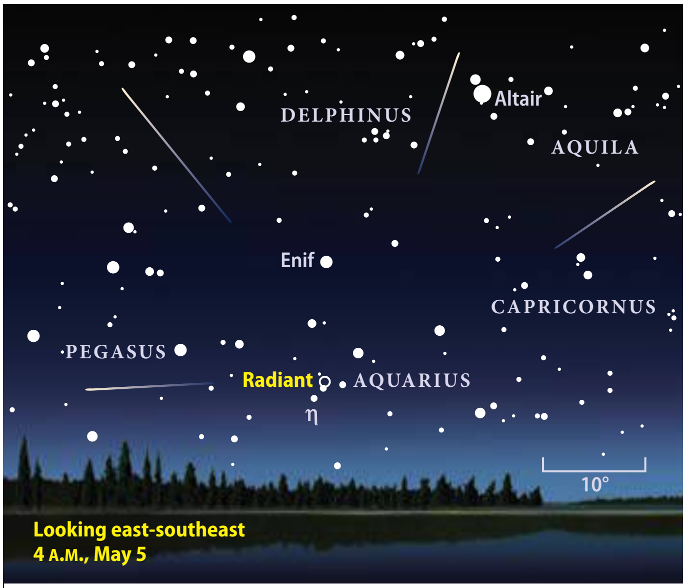
Reaching for the limb

Near the Moon's northwestern limb, you'll find two craters that are rarely seen well. During a favorable libration, however, Babbage and Pythagoras tilt a few extra degrees toward us, offering a unique view of these craters. Such conditions occur beginning May 11 and 12, near Full Moon when the Sun rises over the region. Libration will favor views of the northwestern limb for the next 10 days.

To find this region, start with the prominent crater Plato just off the northern shore of Mare Imbrium. Move north to the finger-like Mare Frigoris, and follow it to its western end. Then, shift your gaze toward the limb, where you'll first see the distinctive classical crater Pythagoras. Babbage lies just southeast of Pythagoras.

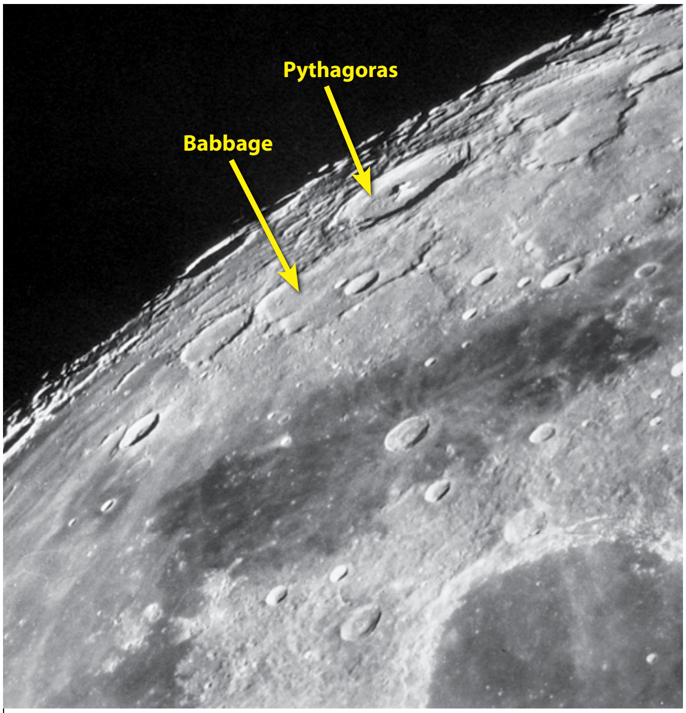
Pythagoras spans 81 miles and shows a foreshortened outline typical of craters near the lunar limb. You will get a nice view of the crater's floor, however. Look for the mile-high central mountain, as well as terracing on the crater's prominent, 3-mile-high walls.

Babbage is an 89-mile-wide walled plain. Its walls are irregular and nestle right up to Pythagoras' southern edge. There's a fresh, sharp-rimmed crater on Babbage's floor, with a smaller crater next to it. Can you spot both of them?



ASTRONOMY: ROEN KELLY

ETA AQUARID METEORS will streak the May 5 predawn sky, delivering a few dozen meteors per hour.



FROM *CONSOLIDATED LUNAR ATLAS* (LPL/UA)

PYTHAGORAS AND BABBAGE show up nicely when the Moon's northwestern limb tilts in our direction this month.

COMETS AND ASTEROIDS

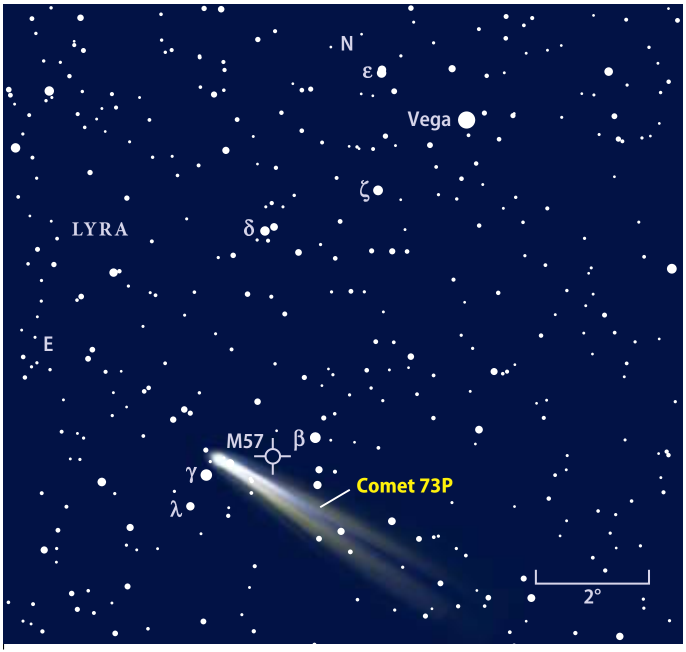
Comet 73P/Schwassmann-Wachmann 3 — possibly the brightest comet in nearly a decade — will be on view during the predawn hours of early May.

A comet's swan song

Neil Young wasn't referring to comets when he sang "It's better to burn out than to fade away." But the sentiment certainly rings true when it comes to observing comets. Astronomers are guardedly optimistic that Comet 73P/Schwassmann-Wachmann 3 will brighten to 2nd magnitude this month, which should be good enough to see from a city park with the naked eye. Our relative positions in space make this a show best viewed after midnight.

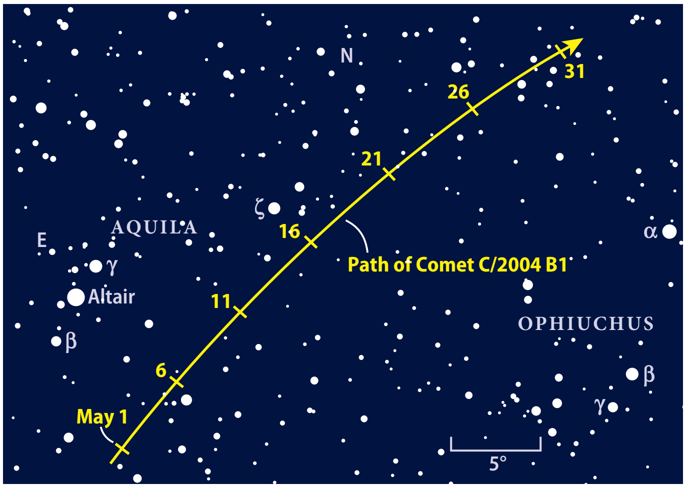
Last October, astronomers recovered component C of this comet's fractured nucleus. Two revolutions of the Sun ago, in the fall of 1995, this primordial snowball split into four pieces. On its last trip through the inner solar system, in January 2001, only three pieces were found. As fragment C heads toward perihelion, its closest point to the Sun, June 6, it may flare up as solar radiation blows it apart.

Don't miss the chance to see this bright fuzzball from a dark-sky location. Small comets like 73P often have a small core surrounded by a huge, faint halo. From the city, the central knot may be all that's visible. The halo could extend more than twice the Moon's apparent size, but it likely will be visible only from the country. Make sure you bring binoculars — they should provide the most impressive view.



ASTRONOMY: ROEN KELLY

THE YEAR'S BRIGHTEST COMET (if predictions hold) will pass near the Ring Nebula (M57) May 8.



ASTRONOMY: ROEN KELLY

COMET C/2004 B1 (LINEAR) traverses the Milky Way this month, when the ice ball should glow at 10th magnitude.

Seize the night

Comet 73P's fragment C will be well-placed for evening skywatchers only until the end of April; unfortunately, before it reaches its peak. During the first week of May, you should delay observing it until the Moon sets. On the 1st, that's around midnight; by the 4th, we're talking 2 A.M. The comet passes close to the Ring Nebula (M57) in Lyra May 8, but the Moon-free observing window comes just as dawn breaks.

After that, things go from bad to worse. The Moon waxes brighter, the comet rises later, and the two head for the same area of sky. Despite deteriorating conditions, you should take every opportunity to observe the comet because it could flare anytime. The Moon passes just 6° away May 22. The comet continues to approach the Sun, to the point where it will be visible only during morning twilight. Assuming there's anything left to see, observers in the Southern Hemisphere will be favored then.

Plan B

In the event Comet 73P/Schwassmann-Wachmann 3 dissolves sooner than expected, another fuzzball should be worth a look. Comet C/2004 B1 (LINEAR) should glow around 10th magnitude as it crosses the Milky Way in Aquila the Eagle. On the morning of May 9, it will pair up with the ghostly disk of the planetary nebula NGC 6781.

To get a decent view of C/2004 B1, observe from a dark sky. During the first week of May, this means watching before dawn. After the 15th, it climbs reasonably high by midnight, when it sits above Altair in the east.

Astronomers seeking life on other worlds first must understand how Earth would appear from far away. ///

BY SARA SEAGER

Searching for signs of life

Somewhere not too far away in the Milky Way Galaxy, an alien civilization may have advanced space telescopes trained on Earth. Does it recognize Earth has conditions to support life? Can it determine whether Earth has life?

◆

Astronomers and engineers are asking these questions as they design an ambitious space telescope with the goal of detecting and characterizing earthlike planets around nearby stars. NASA plans to launch a visible-wavelength telescope called Terrestrial Planet Finder (TPF) in 2014, followed by a complementary, mid-infrared-wavelength version in 2019. To design TPF, scientists must consider what an alien astronomer would be able to learn about Earth from a distance of tens of light-years.

◆

Even looking for a terrestrial planet — a small, rocky world — poses technological challenges, but those are few compared with the problems in identifying a terrestrial planet possessing liquid-water oceans, an "Earth twin." Perhaps surprisingly, such a planet's dimness is not a major concern. TPF will search for Earth twins out to a distance of about 50 light-years. At this distance, an earthlike world would not be too faint for today's telescopes. The Hubble Space Telescope often views galaxies fainter than such a world would be.

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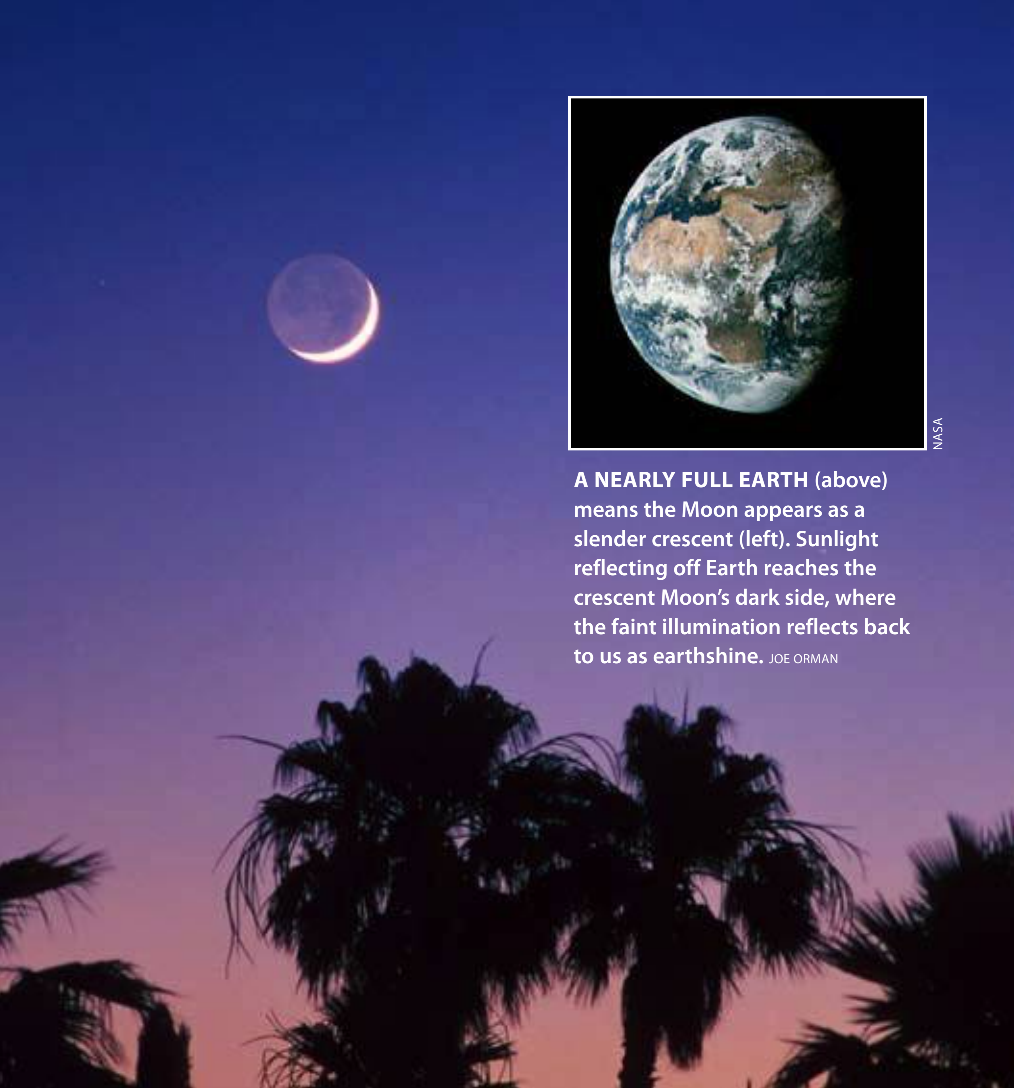
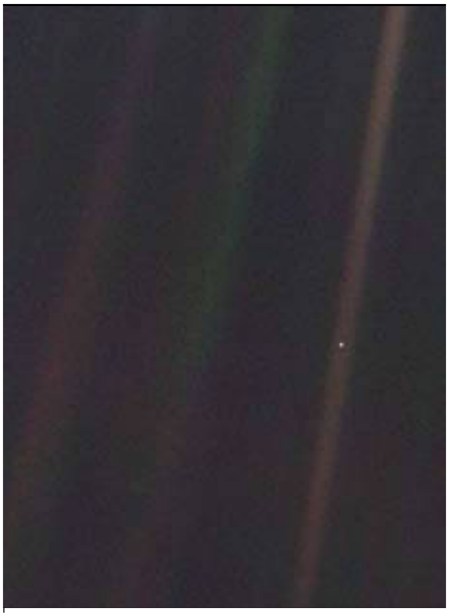
The real problem stems from the brightness of the adjacent parent star. Such a star would shine 10 million to 1 billion times brighter than a planet like Earth, depending on the wavelength of light observed. This huge contrast between faint target planet and bright host star creates a daunting



NASA

A NEARLY FULL EARTH (above) means the Moon appears as a slender crescent (left). Sunlight reflecting off Earth reaches the crescent Moon's dark side, where the faint illumination reflects back to us as earthshine. JOE ORMAN



NASA/JPL

A PALE BLUE DOT — Earth looked nondescript when Voyager 1 imaged it from the solar system's edge, some 4 billion miles away. Light scattering in the camera's optics caused the red and green bands.

technological challenge, and is the most serious issue facing Earth-hunting astronomers. To image an earthlike planet around another star, astronomers must first get rid of the starlight.

Simply imaging an earthlike planet and making basic measurements, such as determining its size or mass, would not be enough, however. For example, Venus and Earth have about the same size, mass, density, and cloud-top temperature. Yet, with a broiling surface temperature of 800° Fahrenheit (700 Kelvin), Venus cannot support life as we know it.

NASA will use pre-TPF space telescopes to measure the frequency of planets with up to a few Earth masses. These missions will detect planets indirectly based on changes in the parent stars. But to find Earth twins, astronomers need to image the planet directly and analyze its spectrum to determine its characteristics and habitability.

Sara Seager *is a staff scientist in the Department of Terrestrial Magnetism at the Carnegie Institution of Washington.*

Earth as an exoplanet

We know of only one example of a habitable world in the entire cosmos: Earth. So astronomers have started their search using Earth as a benchmark.

Even NASA's most ambitious first-generation telescopes designed to view extrasolar Earths will see them as point sources, mere specks of light. For the next few decades, at least, the benchmark "extrasolar Earth" means a spatially unresolved Earth. No details of specific regions of the planet will be visible. All scientists will have to work with is an image averaged over an entire hemisphere.

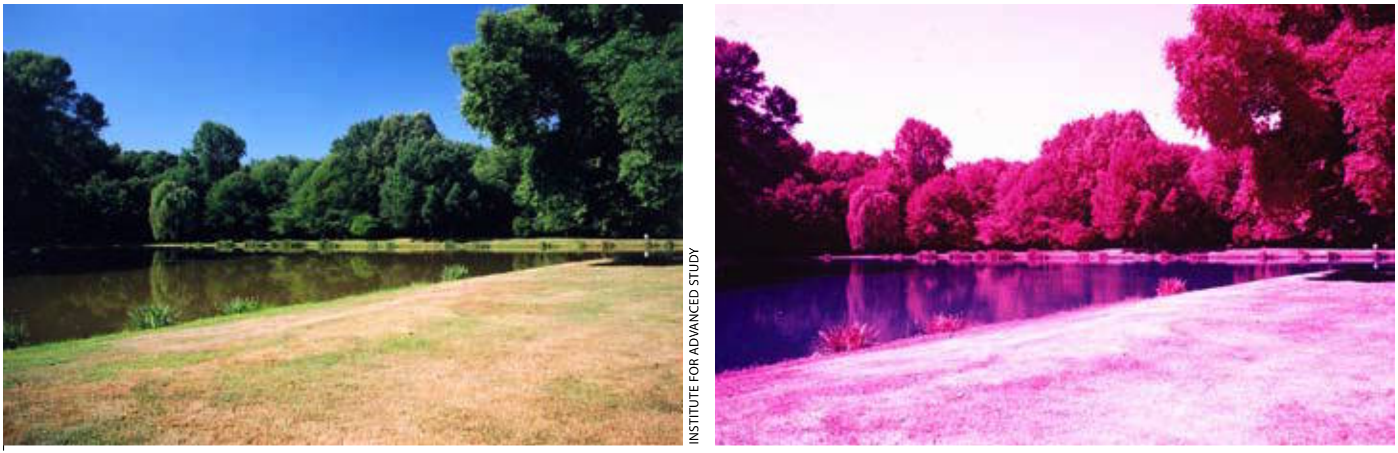
Of course, we know there's a lot more to Earth than a point of light. Our planet has incredibly diverse geography: bright, snow-covered mountains, dense tropical rainforests, vast dark oceans, sparkling sand beaches, and wide swaths of arctic tundra. Earth's weather also varies wildly, with clear skies marred by everything from blizzards to hurricanes to tornados and more — not to mention regular seasonal variations.

A distant observer who sees Earth as a speck in the sky — a "pale blue dot" as Carl Sagan once called it — would miss all those facets. What can we learn from Earth when we view it as a point source?

Send me to the Moon

Ironically, the easiest place to collect data about Earth as an extrasolar planet is right here on our planet. This information comes from earthshine, the faint illumination visible to the naked eye on the dark side of the crescent Moon. Earthshine is sunlight that reflects off Earth, reaches the Moon, and then reflects back to Earth.

EARTH LOOKED STUNNING to the Apollo astronauts, but these details would smear together if an alien civilization pointed its telescopes at our planet. NASA



INSTITUTE FOR ADVANCED STUDY

INSTITUTE FOR ADVANCED STUDY

LIVING VEGETATION strongly reflects near-infrared wavelengths. The photo above was taken with color slide film, the one at right with infrared-sensitive film. If our eyes saw the near-infrared, vegetation would appear a bright red. Notice the dead grass, which appears yellow in the color photograph, does not have a reddish hue in the infrared photo.

Because the Moon is not a good mirror, earthshine provides astronomers with only a spatially unresolved image of Earth. That image is contaminated, however, because earthshine is sunlight reflected off both Earth and the Moon. To study Earth alone, scientists have to remove the Sun and Moon's spectra. Astronomers subtract light from the illuminated part of the lunar crescent — which also contains the Sun and Moon's spectra — to make this correction.

Earthshine contains mostly wavelengths of visible light with a little near-infrared included. The reason: Solar radiation first must penetrate Earth's atmosphere, then reflect off the ground and back into space. The atmosphere absorbs most mid-infrared radiation and prevents it from ever reaching the ground. Also, the Moon's surface radiates heat and appears bright at these wavelengths, swamping any Earth signal.

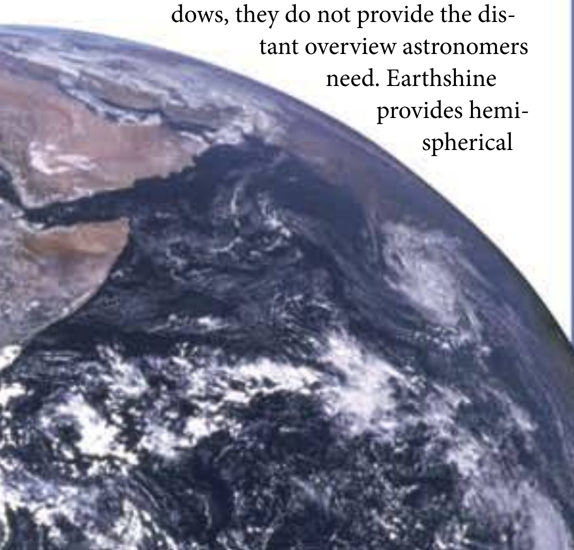
You might wonder why astronomers don't use observations from satellites that image Earth directly. Although these satellites provide excellent images of specific parts of Earth in narrow-wavelength windows, they do not provide the distant overview astronomers need. Earthshine provides hemispherical data that astronomers can measure over a broad wavelength range — just the kind of quantities an extraterrestrial astronomer would see.

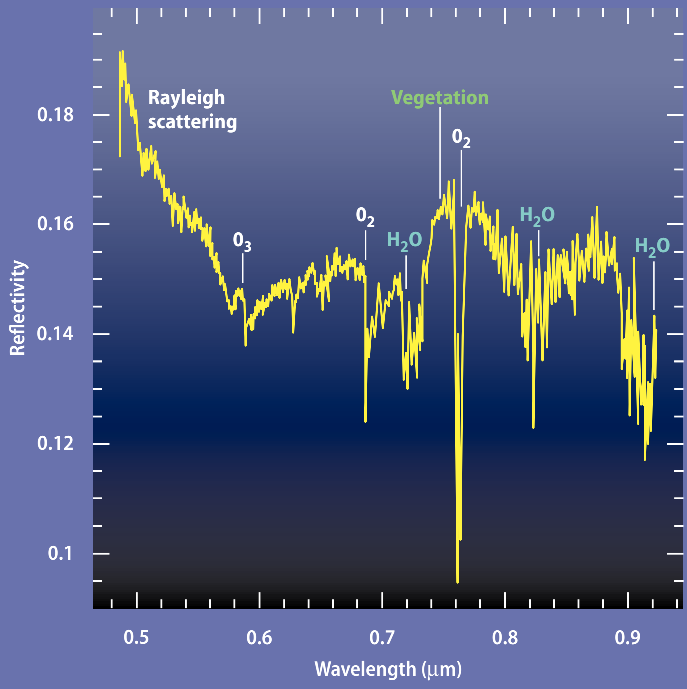
Although earthshine won't allow astronomers to observe Earth like an extrasolar planet at mid-infrared wavelengths, an earthshine spectrum tells us a great deal about our own planet that we can use as a test case. Oxygen, ozone, and water vapor in our atmosphere create several strong absorption features as the molecules absorb photons from incoming sunlight.

None of these molecules could exist on a rocky, terrestrial planet with an atmosphere in thermal and chemical equilibrium. An alien civilization with its space telescopes trained on Earth should recognize our atmosphere as being in a state of extreme disequilibrium, and the molecules present at visible wavelengths suggest activity of a biological nature.

The molecules of life

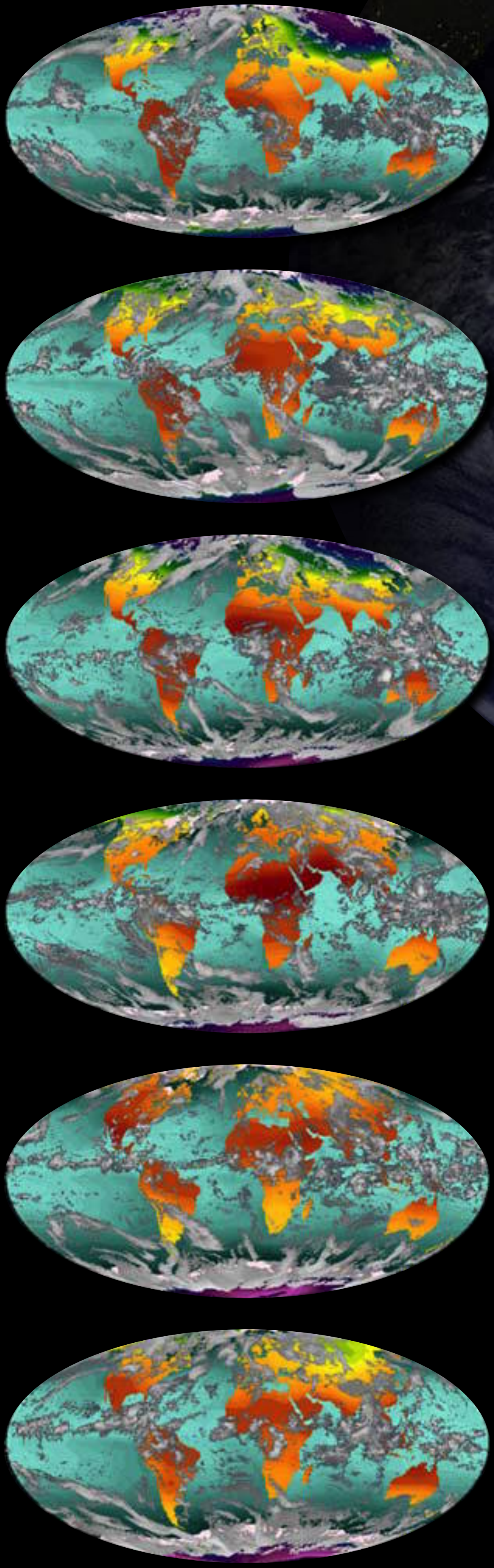
- Oxygen — In its molecular form, oxygen (O_2) is the holy grail "biomarker" astronomers now focus on. It reacts so quickly with other gases that little of it should exist in an atmosphere unless it is replenished continuously and rapidly. The oxygen in Earth's atmosphere comes from photosynthesis by vegetation and photosynthetic bacteria. That's why astronomers consider oxygen an indicator of life.





ASTRONOMY: THEO COBB

AN EARTHSHINE SPECTRUM from Steward Observatory's 2.3-meter telescope on Kitt Peak shows absorption features from water vapor (H_2O), molecular oxygen (O_2), and ozone (O_3). Light scattering off oxygen molecules dominates the spectrum's blue end, while the rise seen at 0.725 micrometer probably comes from vegetation.

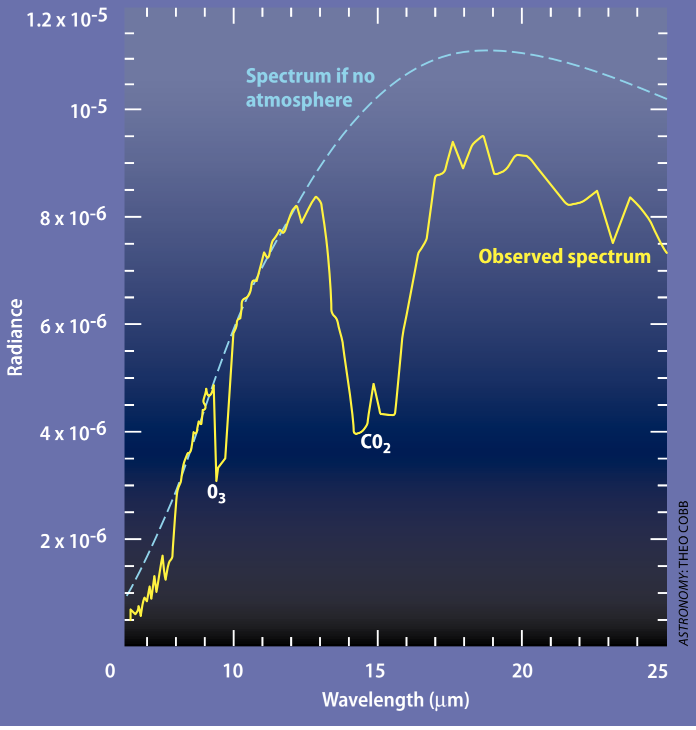


CLOUD PATTERNS ON EARTH stay relatively stable over the course of a year. These images show the patterns on randomly chosen days from 6 different months in the same year. Stable, large-scale features like these will help astronomers determine the rotation rates of spatially unresolved, earthlike planets. NASA

CLOUDS, OCEANS, AND CONTINENTS dominate Earth's appearance from thousands of miles away. NASA'S EARTH OBSERVATORY

To support the interpretation that any detected oxygen has a biological origin, astronomers would like to find evidence of a gas, such as methane (CH_4), that reacts strongly with molecular oxygen and removes it from the atmosphere. Little methane exists in Earth's atmosphere, however, so it can't be detected in earthshine.

- Ozone — A bulked-up version of oxygen, ozone (O_3) arises when solar ultraviolet radiation breaks apart molecular oxygen. The oxygen atoms then recombine to form ozone. Ozone indicates life because it requires the presence of molecular oxygen.
- Water vapor — For a planet of Earth's size, mass, and age, strong bands of water vapor (H_2O) indicate a reservoir of surface water. If the planet did not have such a reservoir, most of the atmospheric water-vapor molecules would have been destroyed long ago — broken apart by the parent star's



A SPECTRUM of the spatially unresolved Earth at mid-infrared wavelengths shows strong absorption features of carbon dioxide (CO_2), ozone (O_3), and water vapor (H_2O). The Thermal Emission Spectrometer aboard Mars Global Surveyor took this spectrum while the spacecraft was on its way to the Red Planet. ASTRONOMY: THEO COBB

ultraviolet radiation. The free hydrogen atoms would have escaped to space, and the oxygen would have combined with other atmospheric molecules or surface rocks. Because all life as we know it requires liquid water, astronomers consider water vapor in a terrestrial planet's atmosphere a prime indicator of habitability.

The color of life

Earth looks like a pale blue dot because molecules in Earth's atmosphere, smaller than the wavelength of light, scatter incoming solar radiation. This shows up as a broad, rising feature at blue wavelengths in the earthshine spectrum. The molecules scatter blue light more efficiently than red light, which makes the sky appear blue. For the same reason, the sky would look blue to an outside observer.

Another color signature arises from the presence of chlorophyll. Plants exhibit a curious spectral signature: Their reflectance changes dramatically at a wavelength around 700 nanometers (nm). At 750nm, vegetation reflects nearly 50 percent of incoming light — a red-edge signature. If our eyes could see a little way into the infrared, Earth would look far different. A forest, grass lawn, or field of crops would appear red and extremely bright, with a glare like that of snow. Scientists who study Earth with remote-sensing equipment use this feature of vegetation to monitor the health of plant communities and to identify plant species.

In the spatially unresolved Earth, the light reflected by vegetation falls well below 50 percent because of cloud cover, immense oceans, and vegetation that only partially covers the continents. Nevertheless, astronomers have tentatively seen this red-edge signature in earthshine by a slight rise in reflectivity around 750nm. A detection of this red-edge feature together with oxygen in the spectrum of an extrasolar planet would bolster the case that the oxygen is of biological origin.

Earth's surface brightness varies dramatically. The glare of sand at the beach stands in stark contrast to the dark ocean. Snow on a ski slope reflects more light than the same slope in summer. Astronomers believe they could measure such a contrast in surface brightness on a hypothetical earthlike planet as the dark oceans and brighter continents rotate into and out of view. In fact, observations from California show earthshine brightens noticeably when Asia's huge land mass rises.

We also know that Earth's weather varies, which causes earthshine's overall brightness to fluctuate by about 10 percent. Ideally, astronomers would be able to determine weather's presence on an Earth twin by detecting this variation.

Although weather patterns change, some remain entrenched. Seattle and the Amazon basin, for example, remain cloud-covered much of the time, while the Sahara Desert stays clear. Atmospheric circulation patterns on Earth manage to keep large-scale cloud patterns relatively constant. This stability would likely allow astronomers to determine Earth's period of rotation, even if they saw our planet as a mere point of light.

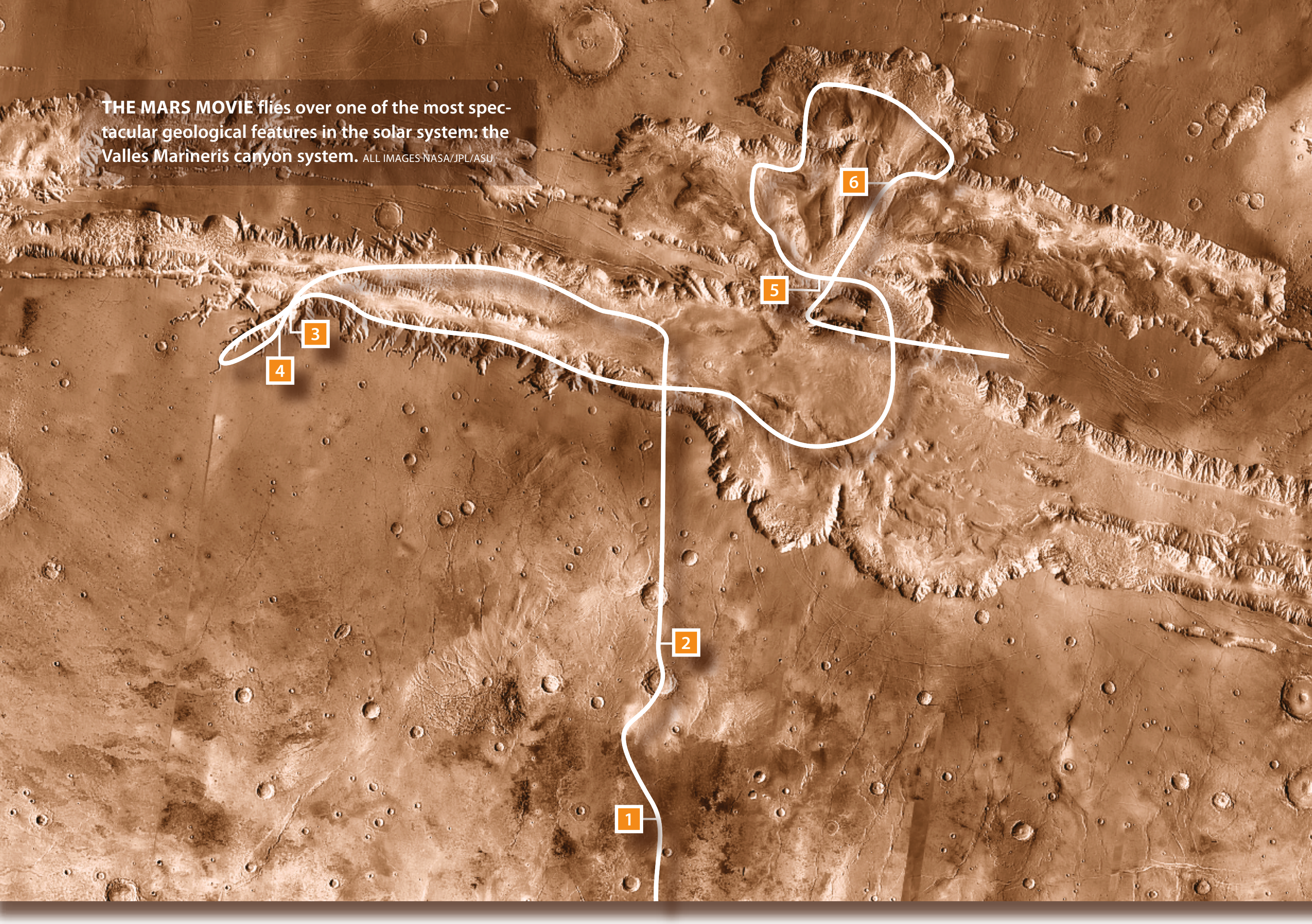
Beyond earthshine

Interplanetary spacecraft that can look back at Earth — without simultaneously looking at the Sun — can give us more information about how Earth would appear as an extrasolar planet. While on its way to Mars in 1996, the Mars Global Surveyor spacecraft did just this. Astronomers saw the strong signature of carbon dioxide (CO_2) at mid-infrared wavelengths. Venus, Earth, and Mars all have strong signals from carbon dioxide, while none of the solar system's gas-giant planets do. That makes CO_2 a good, although not perfect, indicator of a terrestrial planet. Ozone, a by-product of molecular oxygen, also showed a strong mid-infrared absorption feature in the Mars Global Surveyor spectrum.

Understanding what Earth would look like from light-years away requires observations that smear all of the details together. Astronomers must try to extract those details from data and compare them with Earth's "ground truth." This exercise has already produced surprising insights. We've recognized Earth as a pale blue dot from its spectrum. And we've detected strong oxygen and water-absorption features along with color changes induced by vegetation.

Although astronomers have yet to find a single earthlike planet beyond the solar system, they expect that to change radically in the next 2 decades. TPF and other advances may reveal a huge variety of terrestrial planets. Thoroughly understanding Earth as an extrasolar planet is but the first step in making sense of what these planets can tell us. And maybe, just maybe, it can give us the first clues that life exists elsewhere in the galaxy.

ONLINE EXTRA Learn more about TPF by visiting www.astronomy.com/toc.



THE MARS MOVIE flies over one of the most spectacular geological features in the solar system: the Valles Marineris canyon system. ALL IMAGES NASA/JPL/ASU

If an airplane ever flies over Mars, this is the view the pilot would have from the cockpit: Dust devils whirl, craters slip past, a chasm yawns below — then the plane dives for miles toward the bottom before soaring high above to take in the long view. Next it flies up a side canyon, zooms low across a giant landslide, and dodges knife-edge ridges that reach to slice it.

Welcome to Valles Marineris — Mariner Valley — the grandest canyon of all. This gigantic martian feature stretches east-west for about 2,000 miles (3,000 kilometers) just south of the martian equator. Built of several parallel, connecting troughs, Mariner Valley is more than 26,000 feet (8,000 meters) deep and, at its widest, spans 420 miles (700 km). It makes Earth's Grand Canyon — *just* 277 miles (446 km) long, 6,000 feet (1,830m) deep, and 10 miles (16 km) wide — look puny.

Valles Marineris stars in a new video, "Flight Into Mariner Valley," produced jointly by NASA's Jet Propulsion Laboratory (JPL) and Arizona State University (ASU).

The video takes viewers on a roller-coaster ride through part of the canyon. It is based on a new high-resolution mosaic image of Valles Marineris built from more than 500 individual frames. The images were taken at infrared wavelengths by ASU's Thermal Emission Imaging System (THEMIS) instrument aboard NASA's Mars Odyssey orbiter.

"We chose Valles Marineris to make this first mosaic because it's probably the most complex, most interesting feature on the entire planet," says ASU's Phil Christensen, principal investigator for THEMIS. "To understand many of the processes on Mars — erosion and landsliding and effects of water — you really need to have a big-picture view, but still be able to see the details." The smallest features visible in the video are just 330 feet (100m) wide.

THEMIS provided the mosaic, but it took altitude measurements — more than 50 million of them — to turn the mosaic into a landscape mapped in three dimensions. This altitude data came from the Mars Orbiter Laser Altimeter (MOLA) instrument on NASA's Mars Global Surveyor satellite. During 2.4 years of altimetry operations, MOLA wove a dense pattern of accurate elevation measurements across the valley and the rest of Mars.

Silicon magic

Besides MOLA and THEMIS data, one more ingredient was needed to make the video: visualization software. Twenty years ago, animations like this demanded a mainframe computer running complex software that the animator had to write. Today, thanks to the explosive evolution of computer hardware and the booming computer-graphics and animation industries, visualization software and hardware are off-the-shelf items.

Robert Burnham *writes and edits feature stories for the themis.asu.edu web site at Arizona State University's Mars Space Flight Facility.*

Red Planet Rendezvous

Imaging wizards have combined an ultrasharp photo of Valles Marineris and powerful software to produce a stunning aerial tour of the solar system's grandest canyon. /// BY ROBERT BURNHAM

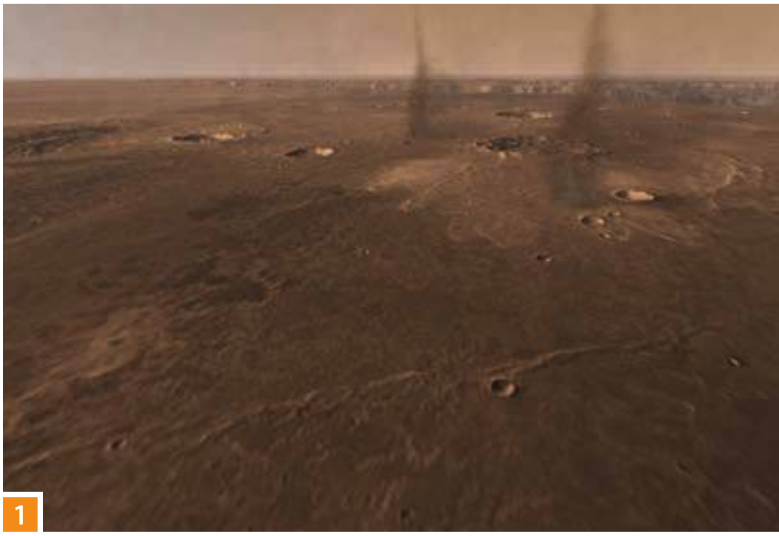
"We've always wanted to conduct virtual geological field trips on other planets," says Eric De Jong, research director of JPL's Digital Image Animation Laboratory, where the work was done. "This is as close as we've gotten so far, and I think it's just the beginning."

For lead animator and project head Zareh Gorjian, also of JPL, "This is a video I've been wanting to make for 15 years. Previous flyover movies have been kind of static — the only thing moving is the camera. In this, we add dust devils and wind gusts and environmental effects."

At ASU, the job of creating the Valles Marineris mosaic began with chief programmer Noel Gorelick, who created the software needed to assemble the mosaic out of the individual THEMIS frames. Mosaic-making finished under Chris Edwards, an undergraduate geology student.

The infrared images, taken during daytime, came back from the spacecraft in the form of strips. Each image captured a swath of ground 20 miles (32 km) wide and up to thousands of miles long. The oldest image in the mosaic was taken February 21, 2002. This was soon after Mars Odyssey began scientific operations, following its arrival at Mars in October 2001. The most recent mosaic image dates from November 5, 2005.

"Valles Marineris is the hardest spot on Mars to mosaic," says Edwards. "This was a tough data set to work with." Because the images were taken over such a long time period, he notes, martian seasonal effects added to the difficulties: "You have to blend images



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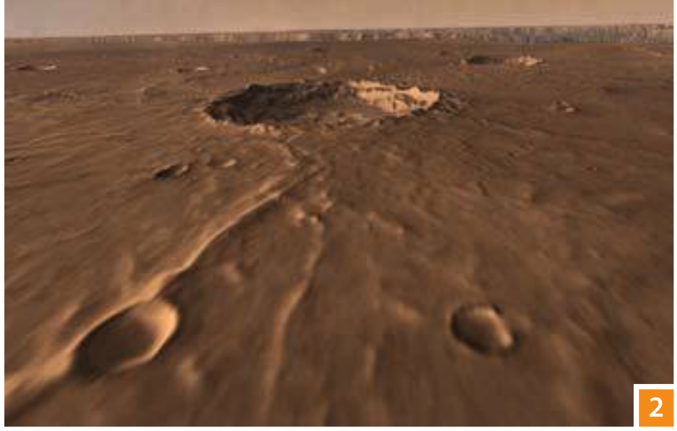
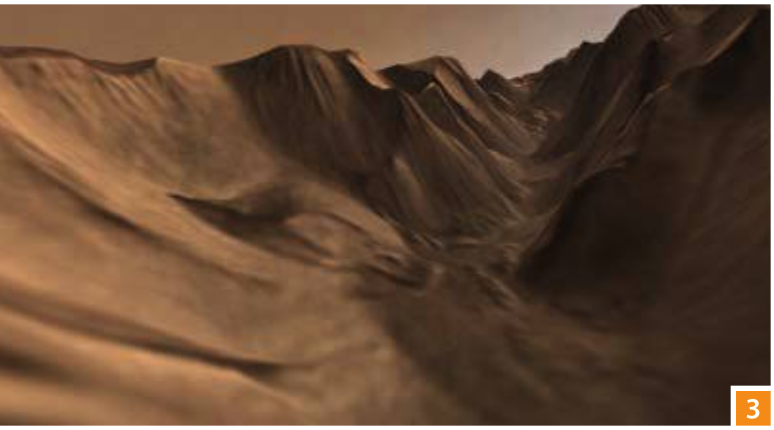
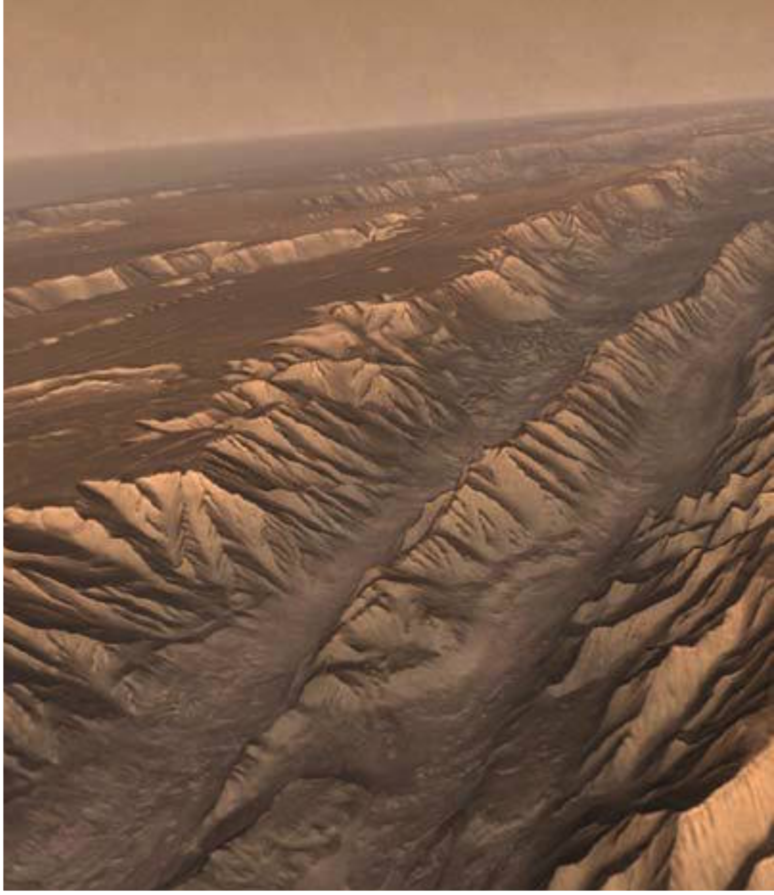
1 **DUST DEVILS WHIRL** across the mesa near the rim of Valles Marineris, the Red Planet's "Grand Canyon." Bigger by far than Earth's Grand Canyon, Valles Marineris is a 2,000-mile-long groove some 26,000 feet deep that scientists think began to form several billion years ago.







2 LAVA FLOWS AND IMPACT CRATERS scar the ground near Valles Marineris. The valley lies on the eastern side of the immense volcanic region Tharsis, and scientists believe the valley's development was linked in some way to volcanic activity there.

3 TWISTING AND TURNING, a tributary side canyon resembles a terrestrial stream valley. Geologists think such canyons form when flowing water beneath the surface undermines the ground and causes a collapse in a process called sapping.

taken at different times of day and different lighting conditions. These produce varying shadows that make the ground look different from one image to the next."

While the mosaic doesn't include every image of the Valles Marineris region taken by THEMIS, all of the images contributed. Whenever a better frame came back from the spacecraft, Edwards substituted it for one with defects, like clouds or haze. In total, the team sifted through 800 images for the mosaic, which combines more than 550 frames. Says Edwards, "This is the best of the best."

At JPL, the Valles video project involved five people full-time for about 3 months, plus others who contributed part-time. The crew included animators and graphic artists Koji Kuramura, Mike Stetson, and Rob Baldwin, who provided up-to-date skills from the movie-making industry. They were responsible for the dust devils, wind gusts, and other features that make the video more realistic.

Jason Craig performed a different role. With a background in astronomy and physics as well as computer graphics, his job was to combine the THEMIS and MOLA data sets into a seamless electronic mesh — a virtual landscape. "At first, merging the data produced stair-step effects like an Aztec pyramid," he says. "But we found a way to create the mesh from the MOLA data, maximizing details and smoothening the results."

More research and tweaking let the team convert the THEMIS images, which display daytime ground temperatures, into a landscape depicted as it would appear to the eye.

Yet another sort of contribution came from Armen Chakmakian, a Grammy-nominated composer and longtime friend of Gorjian. "Armen and I went to high school together," says Gorjian. "As it happened, just when the project got going, he called me and asked if I knew of anything he could work on." Chakmakian's music, written specifically for the video, provides a fitting background and counterpoint to the scenery as it flies by.

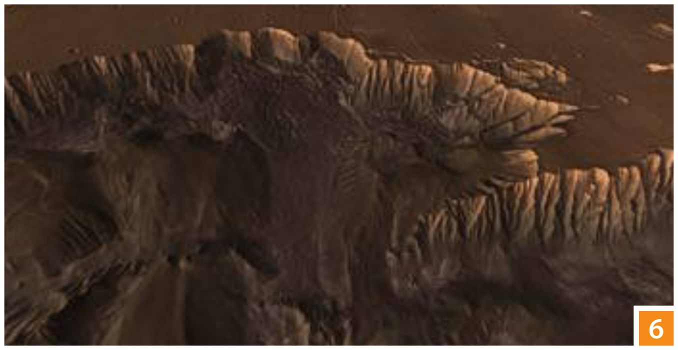
"This was the first JPL animation project that involved off-lab people in such a big way," says Gorjian. And with the spectacular results, it won't be the last, he promises.

Mars history book

Valles Marineris is a striking feature, but to scientists, it's more than just an eye-popping tourist destination. The geological story of Valles Marineris spans much of Mars' history. The valley's development appears closely tied to the growth of Tharsis, a volcanic region just west of the canyon.

Tharsis contains the largest and tallest volcanoes in the solar system and poses geophysical puzzles of its own that scientists have labored for decades to understand.

Geologists think Valles Marineris began to open along geological faults about 3.5 billion years ago. The faulting was caused by tectonic activity in Tharsis. As molten rock pushed into Tharsis from below, the entire region rose. The surrounding crustal rocks stretched and broke into faults and fractures.



4 **WIDENED BY LANDSLIDES** and cut by side canyons, Mariner Valley includes several linked troughs connected by broad openings. The canyon's overall straight lines suggest the major process that created it was geological faulting.

5 **A CANYON IS A HOLE** in the ground, but rocks, fine-grain sediments, and other deposits have refilled parts of Valles Marineris with layered debris. Is it volcanic ash? Windblown material? Lake-bottom sediments? Maybe all of these — geologists don't know.

6 **BURIED IN THE ROCKS** of this Grand Canyon of All the Planets lies a history book of Mars that scientists have just begun to open.

As cracks opened, the ground sank, much as the keystone in an arch drops when the ends of the arch are moved apart. The faulting also opened paths for subsurface water to escape, undermining the ground and enlarging the fracture zone. In countless places, the valley's steep, newly exposed walls became unstable, causing landslides that further widened the canyon.

It's not clear when the valley stopped growing — and in a sense, it still hasn't. Even today, small landslides undoubtedly occur, but it appears the main activity came to a halt roughly 2 billion years ago.

Within the valley lie extensive sedimentary deposits that show evidence of layering. What formed these "interior layered deposits," as scientists call them, is one of Mars' biggest geological mysteries. Some layers appear dark and may be hardened volcanic ash; other layers show features called yardangs produced by wind erosion, which points to soft and easily eroded materials. The layered deposits tantalize scientists, who suspect the material contains many pages in the martian geological record book.

The Valles video certainly provides a thrilling ride, but do such videos offer any value apart from that?

It's a fair question. Perspective views and animated flyovers were once derided by planetary scientists as little more than eye-candy for the news media and public. But beginning about 15 years ago, scientists reconsidered their value.

For one thing, such views — despite vertical exaggerations such as the factor of 2.5 used here — provide the you-are-there immediacy sought by any field geologist on Earth. Also, perspective views and animations can help make relationships clearer between rock layers separated by miles across a canyon, for example. Augmented with other data, such views can also suggest the sequence of events in a given locale. Finally, because humans are skilled at interpreting the world visually, exploring a landscape through images plays into our cognitive strengths.

Striking as it is, the Valles video is hardly an end-point, says JPL's De Jong. Robotic spacecraft that collect high-resolution images of parts of a large feature (such as Valles Marineris) could be used to make a virtual experience even more real.

Think of it, he says: "High-resolution images inserted in a coarser-scale mosaic would let you drop in on the areas as if you were landing there and doing a walk-around." And with the right data, he adds, "You could pull out a virtual hand lens and examine rocks at the site on a scale of inches, even fractions of an inch. That's probably the next step in the evolution."

Even if a next-generation rover like Mars Surface Laboratory (MSL), due for launch in 2011, never goes into Valles Marineris, we can still prowl through part of this awe-inspiring valley now. Says De Jong, "Everybody wants to share in the exploration, and this video gives them the chance." A

ONLINE EXTRA Experience the ride — go to www.astronomy.com/toc to view the Valles Marineris flyover movie.

ASK ASTRO

Astronomy's editors and experts from around the globe answer your questions about the cosmos. This month: How does material escape a black hole, and how many dimensions are there?

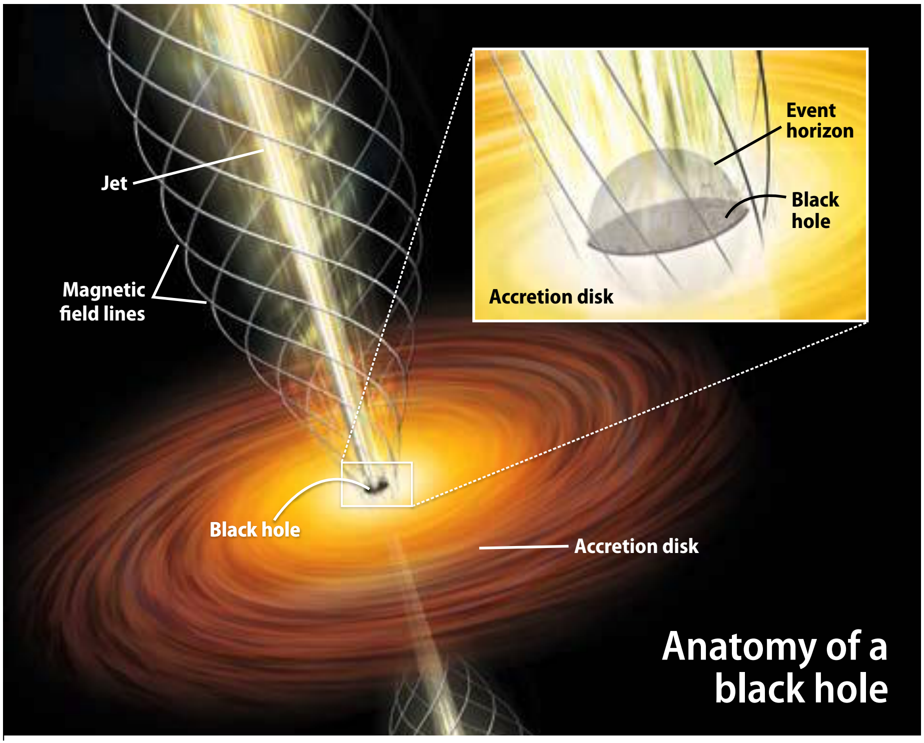
ESCAPING THE PULL

Q: If a black hole's gravity is so great that not even light can escape its pull, why do some black holes, like quasars, emit jets of material? — **BEN HANSELL,** SAN FRANCISCO

A: Black holes are regions where matter is extremely, mind-boggingly compressed into zero volume. According to Einstein's theory of general relativity, neither matter nor light can escape these dense objects. Hence, they are called black holes. However, the distance a black hole's strong gravity reaches is limited and is called the event horizon. **Light is not emitted from the black hole itself but from an accretion disk of gas and dust that forms around a black hole far from its event horizon.**

The size of the event horizon depends linearly on the black hole's mass. For a black hole the mass of our Sun, that distance (as measured from the black hole's center) is only 1.9 miles (3 kilometers). So, if you were transported to within that distance, say 1.2 miles (2 km) of such a black hole's center, you would be swallowed by it.

Astronomers divide black holes into two groups: stellar-mass black holes (with masses between 1 and 10 times our Sun's) and supermassive black holes (with masses millions to billions times that of our Sun).



Anatomy of a black hole

WHEN MATERIAL in the accretion disk spirals toward the black hole, gas and dust collide. Friction heats this material, making it shine brightly. The powerful jets associated with black holes originate from just outside a black hole's event horizon. These jets align themselves with the black hole's magnetic field, perpendicular to the accretion disk. *ASTRONOMY:* ROEN KELLY

Quasars are young galaxies with supermassive black holes characterized by extreme luminosities — on the order of trillions of times that of our Sun.

The light you see is created when rotating material moves toward the black hole's center. The gas and dust follow a path similar to one water takes when you pull the plug from a drain. The water spirals toward the drain and, the closer it gets to the center, the faster it rotates. The material forms a disk around the black hole. Friction heats the material and makes it shine brightly. This is one way astronomers can observe black holes: by their effect on surrounding material.

Astronomers have observed many quasars firing off jets at nearly the speed of light. These jets are aligned 90° to the black hole's accretion disk, and the material in the jet is launched outside the event horizon. The formation processes of these jets are not completely understood, but astronomers believe strong magnetic fields aligned 90° to the accretion disk channel the jets. Channeling the ejected material outside the event horizon requires powerful forces, like those exerted by strong magnetic fields.

Our own Milky Way harbors a central black hole with a mass of about 3 million Suns. Astronomers, however, haven't detected jets there, which implies the black hole is starved. If little mass reaches the black hole, not much can be ejected.

— **MARYAM MODJAZ,** HARVARD UNIVERSITY, CAMBRIDGE, MASSACHUSETTS

WHO'S COUNTING?

Q: Do we know how many dimensions there are?

— **DALE GLABACH**

A: Physicists claim to have a beautiful and consistent theory of quantum gravity, yet they can't agree on the number of dimensions. **Some say 10, and some**

say 11. Actually, our universe may have both — 10 and 11 dimensions.

The classical notion of space-time loses its meaning in quantum theory. It's replaced by a more general concept, a "quantum space-time" where dimension is not a well-defined notion. We know a great deal about certain quantum space-times, which have many precise properties, but dimension is not one of those properties.

String theorists know the number of dimensions needed to describe the world we live in is greater than the basic four: the three of space, and one relating to time. The cases in which we have 10 or 11 are especially simple. They are simpler because the internal dimensions — namely the dimensions beyond the four we see — can be relatively large. (By relatively large, I mean larger than the size of the string but smaller than any distance we can experimentally detect today.) We can describe them using geometrical language.

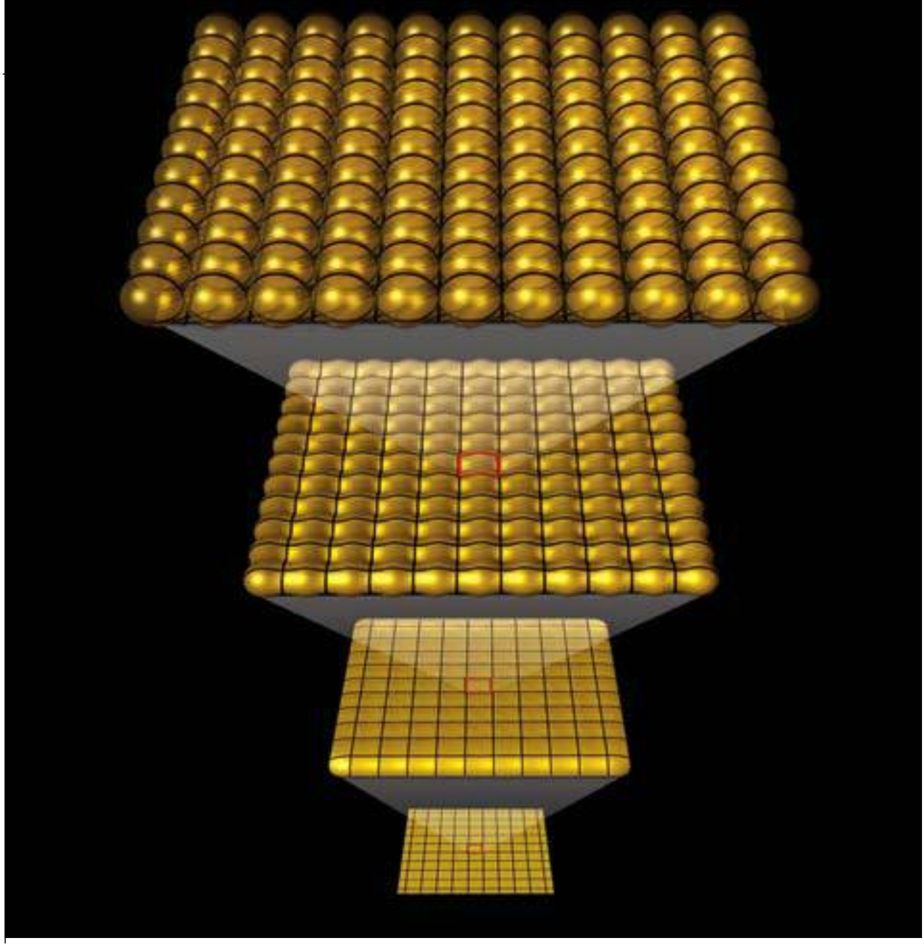
What's the difference between 10 and 11? The simplest string theory is 10-dimensional. Strings can interact with each other, and if the interaction is large, the theory seems hard to describe. However, when strings interact strongly, a new dimension opens up, and we have a theory in 11 dimensions: the 10 we started with plus an extra circle. In 11 dimensions, we do not have strings; we have membranes. Membranes wrapped along the 11th dimension give rise to strings.

We do not know yet whether a description in terms of 10 or 11 dimensions is more appropriate for our universe. But these are simply two different possibilities for the internal geometry. Because the geometry of the internal space is quantum mechanical, asking what dimension the space is might not be the right question.

IN THE KNOW

QUANTUM MECHANICS
First introduced by Max Planck in 1900, the theory states that energy is emitted or absorbed in discrete packets, or quanta; the physical laws that describe the behavior of matter at the atomic and subatomic level.

Zooming in to the quantum level


ASTRONOMY: ROEN KELLY

AT EXTREMELY CLOSE DISTANCES, the quantum level, the concept of dimension may break down. Additional dimensions could be curled up in rings or spheres; and the closer we zoom in, the more detail we see.

Recent developments have shown that the concept of space-time itself breaks down at the quantum level and will have to be replaced by some other concept at this level. Think of a lake's surface. Classical physicists describe how waves propagate on this surface, state whether an observer is above or below the surface, and pay attention to other macroscopic qualities.

On the other hand, when we look at the lake with high resolution, we see the individual water molecules — the surface of the lake becomes less sharp. In fact, the surface is not a well-defined concept at the atomic level. Molecules constantly move between the water and air. We can talk only about the surface of the lake at macroscopic distances.

The same happens with space-time; we can use the standard geometric description only at far enough distances. Of course, in the case of space-time, we would need to go to distances smaller than the distances that are experimentally accessible today in order to see the concept breaking down. But string theory predicts space-time loses its meaning at short distances, just like the lake's surface does. This does not mean we cannot describe the system. In the case of water, we have a well-defined description of the system in terms of the water molecules. Similarly, in the case of space-time, we have a good description of what is going on, at least in some special circumstances.

In a quantum space-time, the dimension might not be well-defined. When the space in question is small, that space can alternate between different dimensions. — **JUAN MALDACENA,** INSTITUTE FOR ADVANCED STUDY, PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

For amateur and professional astronomers alike, this face-on beauty ranks as a celestial showpiece. /// BY RAYMOND SHUBINSKI

All about the Whirlpool Galaxy

During spring and summer, an incredible sight awaits observers: a bright spiral galaxy composed of billions of stars. The Whirlpool Galaxy (M51) ranks as one of the best-known and most often observed of celestial objects, perhaps second only to the Andromeda Galaxy.

French comet-hunter Charles Messier (1730–1817) discovered M51 October 13, 1773. The galaxy glows softly at magnitude 8.4. Along with its companion, NGC 5195, the Whirlpool makes a fine target through any size telescope. The near face-on view of this spiral galaxy led to its common name, the Whirlpool.

The Whirlpool Galaxy's place in the history of astronomy is closely tied to the development of ever larger telescopes and ever more sensitive recording instruments. For many years after Messier found this object and placed it on his famous list, the best telescopes continued to show it as merely a fuzzy and indistinct patch. It was referred to simply as a nebula. (*Nebula* is a Latin word meaning "cloud" and was applied to any indistinct object beyond the resolving ability of early telescopes.)

German-born English astronomer William Herschel (1738–1822) achieved worldwide fame after he discovered Uranus in 1781 with his homemade telescope that sported a 6-inch mirror. Once Herschel became Royal Astronomer, he was financially able to quench a desire that strikes every astronomer — amateur or professional — aperture fever.

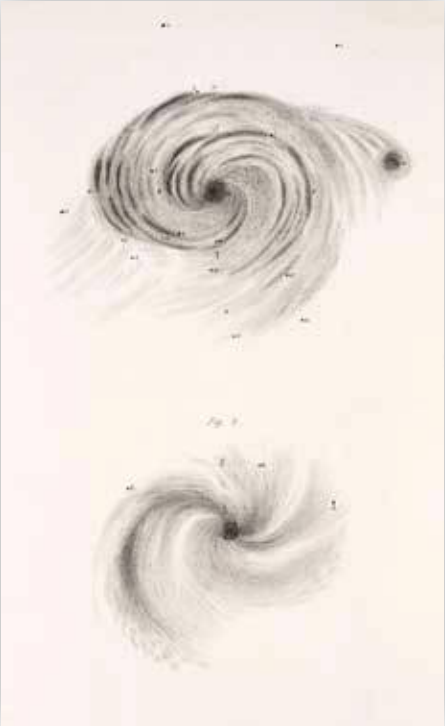
Herschel built reflecting telescopes rather than refractors, but he took them to a new realm of quality. In 1789, he built a telescope with a tube 40 feet long and a speculum mirror 48 inches across. The scope was a monster and difficult to maneuver, but the mirror was the real problem. Speculum is an alloy of copper and tin that can take a fine polish on its surface, but it tarnishes quickly. Herschel observed M51, but he said little about any visible structure. After Herschel, other astronomers studied the Whirlpool.

In the mid-19th century, astronomy as a profession didn't really exist. With a few exceptions, the study of the heavens was the domain of wealthy gentlemen, such as William Parsons, born in 1800 to the Second Earl of Rosse in Ireland. The young William was elected Lord Oxmantown while at Oxford and later, following his father's death, became the Third Earl of Rosse.

At Oxford, Parsons developed an interest in astronomy. When he returned home to Birr Castle, he was determined to outdo the optical feats of William Herschel and build his own telescopes. Training the men on his estate in optics and mechanics, Parsons — with considerable help — constructed a telescope 56 feet long with a speculum mirror 6 feet in diameter. The tube was so big, it had to be mounted between two massive walls 50 feet high. The tube was aligned north-south and could only be raised or lowered.

Rosse tried 5 times to cast the great mirror before he obtained satisfactory results. Knowing the problems Herschel had experienced with mirror-tarnish in his telescopes, Rosse cast a second mirror to use as a backup while the other was being repolished. He completed the telescope in 1845, and it soon became known as the Leviathan of Parsonstown.

In the spring of 1845, Rosse made some preliminary observations of M51 through his Leviathan accompanied by excellent drawings. But then famine struck Ireland. This calamity caused widespread death and misery and had an unexpected retarding effect on the science of astronomy.



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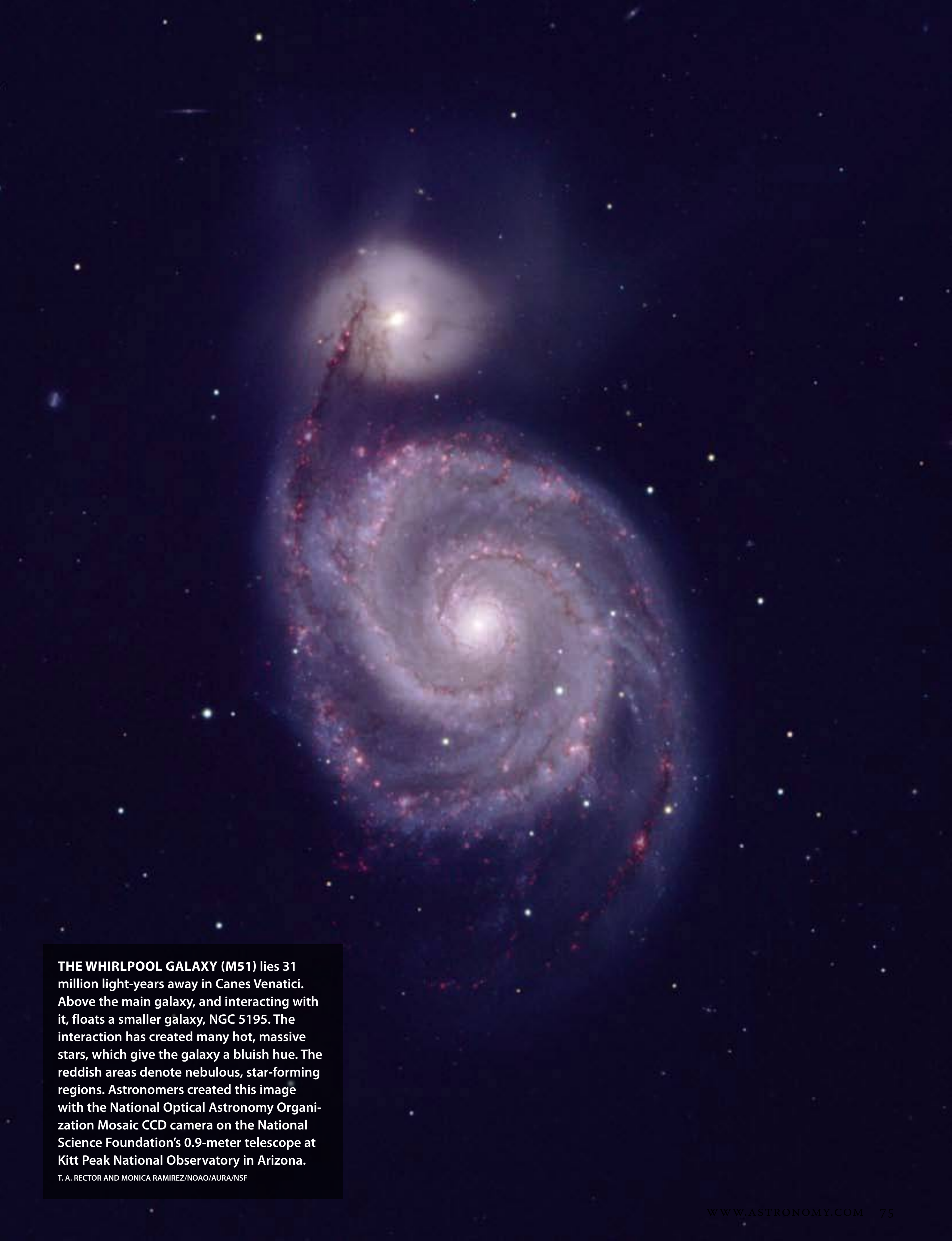
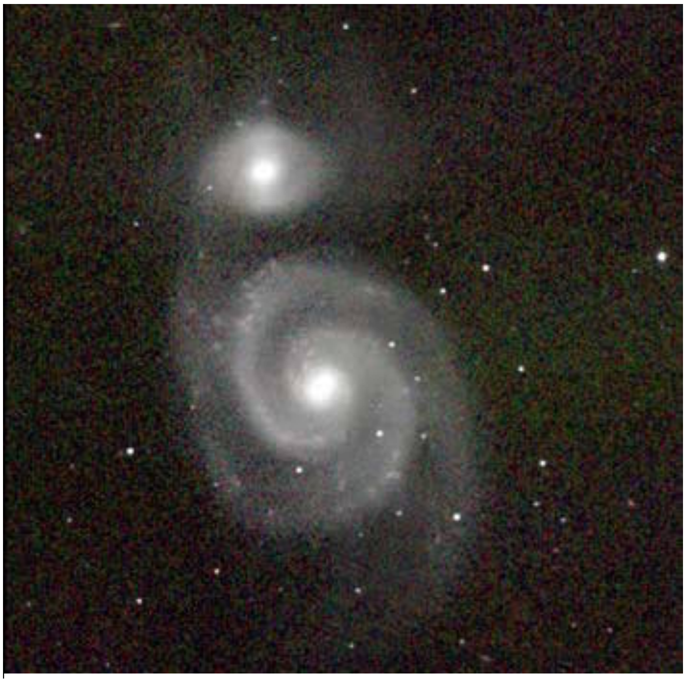
THIS DRAWING of the Whirlpool Galaxy (M51) was the first image to show spiral structure in any celestial object. William Parsons, the Third Earl of Rosse, constructed a 72-inch reflecting telescope called the Leviathan of Parsonstown, the location of Rosse's Birr Castle. Rosse drew this while observing the Whirlpool Galaxy through his Leviathan.

Raymond Shubinski *is the director of Science City/Attractions in Kansas City, Missouri, and a long-time galaxy observer.*



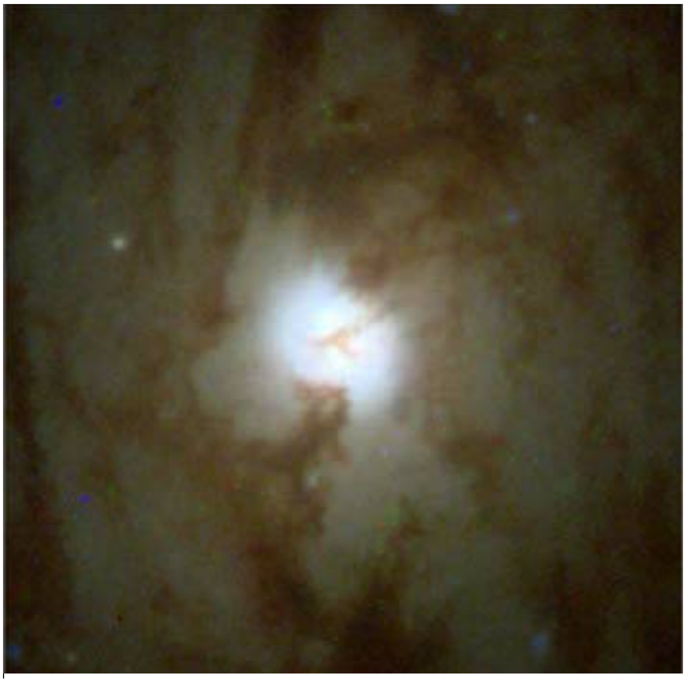
THE WHIRLPOOL GALAXY (M51) lies 31 million light-years away in Canes Venatici. Above the main galaxy, and interacting with it, floats a smaller galaxy, NGC 5195. The interaction has created many hot, massive stars, which give the galaxy a bluish hue. The reddish areas denote nebulous, star-forming regions. Astronomers created this image with the National Optical Astronomy Organization Mosaic CCD camera on the National Science Foundation's 0.9-meter telescope at Kitt Peak National Observatory in Arizona.

T. A. RECTOR AND MONICA RAMIREZ/NOAO/AURA/NSF



2MASS

IN NEAR-INFRARED LIGHT, M51 looks similar to what you'd see through a large telescope. The Two Micron All-Sky Survey (2MASS) telescopes reveal light originating from relatively old stars in galaxies such as M51. Such stars trace the distribution of stellar mass. Active star formation appears as knots in the spiral arms.



N. PANAGIA (STScI, ESA)/NASA

A DENSE REGION of young stars one-tenth the Sun's age glows in the Whirlpool Galaxy's nucleus. This region measures a mere 80 light-years across, compared to M51's 65,000 light-year diameter. The dark Y superimposed on the nucleus is dust, which blocks light from more distant stars.

Being a member of England's House of Lords, Rosse went to London to plead for aid. He spent the next 3 years in England. By the time Lord Rosse returned to his great telescope in 1848, a million Irish had starved and another million had fled the stricken land.

Lord Rosse returned to his observing, but it was 1850 before his results appeared in the Royal Society's *Philosophical Transactions*. His drawings of M51 show it to be the first object in which definite spiral form could be observed. His article created a sensation. The Leviathan clearly showed structures no one had glimpsed before. Lord Rosse was convinced spiral nebulae were not gaseous, as Herschel had believed. Try as he might, however, Rosse could never resolve them into individual stars. It would be many years before the true nature of these objects was confirmed.

Find the Whirlpool

You need only a small telescope to see M51, which lies between Boötes and Ursa Major in the northern constellation Canes Venatici the Hunting Dogs. Canes Venatici is the creation of 17th-century astronomer Johannes Hevelius. This constellation appears rather dim. Its brightest star is Cor Caroli (Alpha [α] Canum Venaticorum). Cor Caroli is one of the few stars to retain a fairly modern name, in this case assigned by English astronomer Edmond Halley (1656–1742). In addition to M51, the constellation contains four Messier objects: M3, M63, M94, and M106. With the exception of M3, these objects are spiral galaxies. Because of its position far from the Milky Way, Canes Venatici is strewn with galaxies, many of them faint.

LORD ROSSE WAS convinced spiral nebulae were not gaseous, as Herschel had believed.

To find M51 the "old fashioned" way, start with Benetnasch (Eta [η] Ursae Majoris), the star at the end of the Big Dipper's handle. About 2° below Benetnasch, just over the border into Canes Venatici, lies 4.7-magnitude 24 Canum Venaticorum. Less than 2° south of 24 CVn is a smudge of 8th-magnitude light that marks M51. In 6-inch or smaller telescopes, you'll find it difficult to detect any spiral structure in the Whirlpool Galaxy. The most pleasing results come from observations made with 12.5-inch or larger scopes.

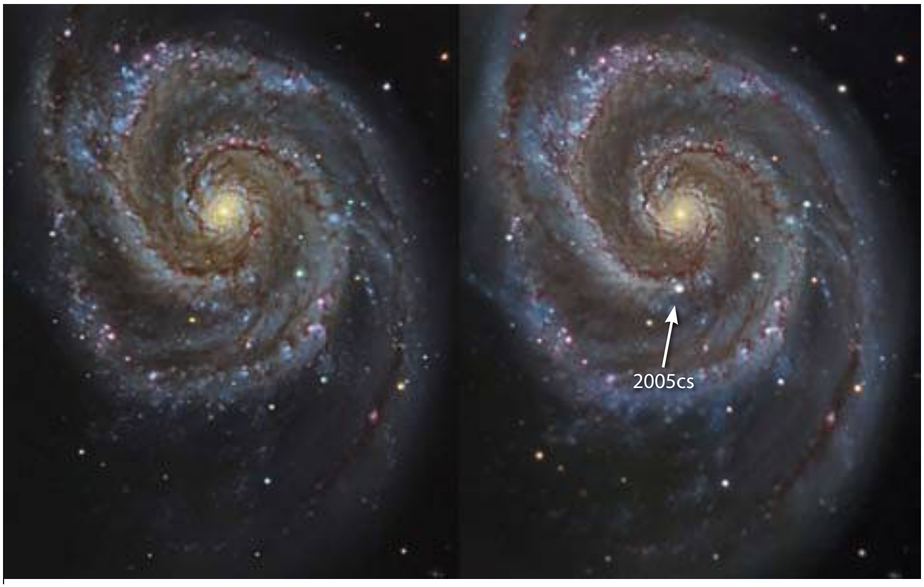
Tackling M51's mysteries

For decades after Lord Rosse made his observations, astronomers carefully studied M51 and other spiral nebulae to discern their nature. Even photography couldn't resolve the question, and it divided astronomers: Were all nebulae clouds of gas forming stars? Were spiral nebulae evolved nebulae condensing into solar systems? Were they part of our galaxy or far beyond the realm of our Milky Way? The answers to these questions lay in sciences which, in the mid-19th century, were not yet joined with astronomy.

"We can imagine the possibility of determining the shapes of stars, their distances, their sizes, and their movements; whereas there is no means by which we will ever be able to examine their chemical composition," French philosopher Auguste Comte (1798–1857) wrote in 1830. He never guessed the secrets of stars and nebulae lay hidden in their chemistry.

In the late 1850s, German scientists Gustav Kirchhoff (1824–1887) and Robert

A CLOSE-UP of the Whirlpool Galaxy shows a small part of one of its spiral arms. This image reveals brilliant blue clusters of young, hot stars embedded in vast red clouds of glowing hydrogen and darker dust. NASA/ESA/S. BECKWITH (STScI)/HUBBLE HERITAGE TEAM (STScI/AURA)



R. JAY GABANY

SUPERNOVA 2005cs erupted in the Whirlpool Galaxy approximately 31 million years ago. Light from this event reached Earth June 28, 2005, when Wolfgang Kloehr of Schweinfurt, Germany, was first to spot it. Astroimager R. Jay GaBany of San Jose, California, captured M51 before and during (arrow) 2005cs' outburst.

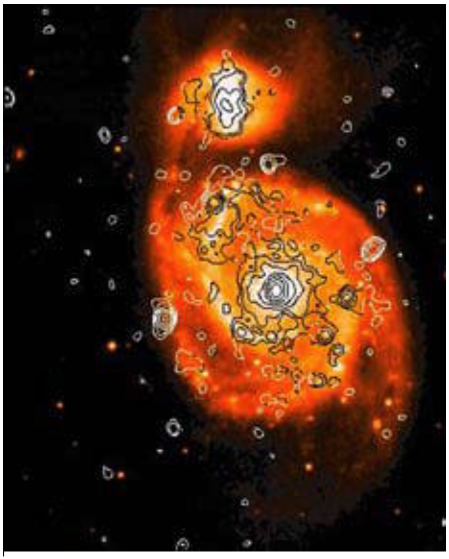
M51'S SPIRAL ARMS explode with detail in this image, which combines exposures from the 0.9-meter Kitt Peak National Observatory Telescope and the Hubble Space Telescope. By stacking these images, astronomers can show sharp features normally too red to be recorded by optical telescopes. N. SCOVILLE (CALTECH), T. RECTOR (U. ALASKA, NOAO) ET AL./HUBBLE HERITAGE TEAM/NASA

Bunsen (1811–1899) were developing the science of spectroscopy to examine mineral specimens. Their discovery of bright-line spectra from heated gas not only opened a new window for the study of earthly elements but also opened a window on the heavens unanticipated by Comte.

William Huggins (1824–1910), a London dealer of fine silks and linens, was deeply interested in astronomy. He adapted the newly invented spectroscope for astronomical use and, in 1864, found that some nebulae, such as the Orion Nebula (M42), produce a bright-line spectrum. This discovery provided a key to understanding the universe's physical nature.

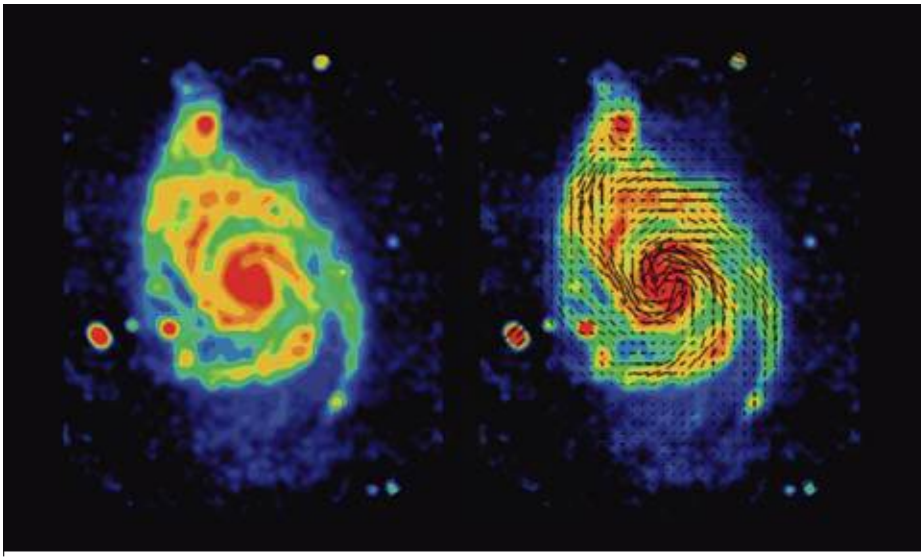
When astronomers turned the spectroscope toward spiral nebulae, they were in for a surprise. Rather than the bright-line spectrum of heated gas, they saw a continuous spectrum of colors overlaid with thin black lines — absorption spectra. German astronomer and telescope-maker Joseph von Fraunhöfer (1787–1826) discovered similar lines early in the 19th century. Kirchhoff had used the spectroscope to interpret these lines and determine the Sun's chemical composition. The spectra of spiral nebulae indicated they were made of an aggregate of stars rather than a gas cloud. Yet the telescopes of the time could not resolve individual stars.

By the turn of the 20th century, the debate was heating up, and astronomers split into two camps. The real question was a matter of scale. Were all stars and nebulae part of our galaxy, which represented the universe as a whole? Or was the Milky Way an "island universe," adrift with other such



ROSAT

X-RAY observations of M51 show most of the galaxy's X-ray emission originates from hot gas. The remaining X rays come from bright binary systems that contain a black hole and a supernova remnant.



NRAO/AUI

RADIO OBSERVATIONS reveal M51's overall magnetic-field structure. The left image combines observations with NRAO's Very Large Array near Socorro, New Mexico, and the Effelsberg 100-meter radio telescope in Germany. The image to the right adds magnetic vectors that show the orientations of regular magnetic fields. The field lines follow the spiral arms and are strongest at their inner edges.

island universes? In the latter model, spiral nebulae such as M51 represented vast cities of stars at incredible distances.

This debate peaked April 26, 1920, before the National Academy of Sciences, when American astronomers Heber D. Curtis (1872–1942) and Harlow Shapley (1885–1972) met to argue the question. Curtis had been photographing celestial objects with the 36-inch Crossley telescope at Lick Observatory in California and had cataloged hundreds of spiral nebulae. He concluded they were galaxies in their own right. Shapley, on the other hand, was surveying globular clusters and using the results to help place the Sun and solar system within the Milky Way, which he considered to represent the entire universe.

The title of the debate was "Scale of the Universe," and it became something of a media event. Shapley argued the Milky Way was vast in scale, and the solar system lay far from its center. Curtis insisted on a smaller distance scale for the Milky Way with the solar system near its center. According to Curtis, spiral nebulae lay at vast distances and were not part of our local system. Only a few years would pass before the debate was resolved.

Classifying the Whirlpool

On November 1, 1917, the 100-inch Hooker reflecting telescope saw first light at Mt. Wilson Observatory in California. At long last, a new telescope held the world's size record, overtaking Lord Rosse's Leviathan. In the 1920s, Edwin Hubble (1889–1953) used the 100-inch scope to resolve individual stars in the Andromeda Galaxy (M31). Hubble also measured the light curves of Cepheid variables in M31, which allowed him to develop an estimate of Andromeda's distance. He showed clearly that M31, M51, and other spiral nebulae are galaxies far outside the Milky Way.

HE SHOWED CLEARLY that M31, M51, and other spiral nebulae are galaxies far outside the Milky Way.

Hubble went on to develop a classification system for galaxies. His "tuning fork" diagram separated elliptical, spiral, and irregular galaxies based on shape. He classified M51 as an Sc-type galaxy, the *S* for spiral and the *c* for the amount of openness of its spiral arms. The face-on view of M51 gives us a chance to look deeply into the pinwheel of stars that compose this galaxy.

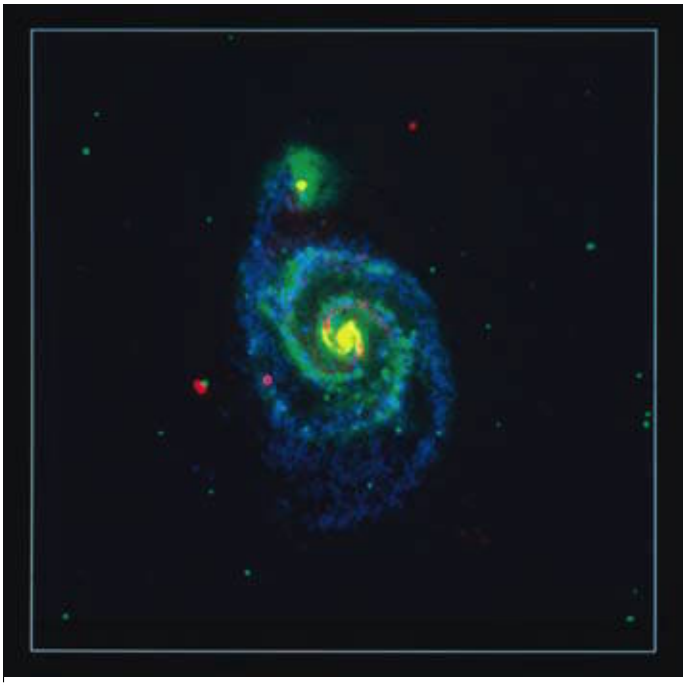
A close look at M51 shows a "hook," first described in 1781 by Pierre Méchain (1744–1804), an observing companion of Charles Messier. This hook is now designated NGC 5195, the Whirlpool's companion galaxy. A bridge, or streamer, of stars appears to connect the galaxies. For a long time, astronomers were unsure if the two galaxies were related, but recent studies confirm this idea.

M51 lies approximately 31 million light-years from the Milky Way and belongs to a small group of galaxies that includes the Sunflower Galaxy (M63). It's now clear that NGC 5195 — also a spiral galaxy seen face-on — collided with M51. Astronomers think this event happened roughly 280 million years ago. The encounter has had a dramatic effect on both galaxies.

M51 appears distorted. Most face-on spiral galaxies appear almost circular, yet M51 looks distinctly elliptical. This is the result of gravitational tidal forces that have "squeezed" M51 and torn NGC 5195 apart. This interaction had other dynamic effects on M51. Color images of this galaxy show a great deal of star formation highlighted by the blue color of the spiral arms. New star formation also occurs along the streamers that connect the two galaxies.

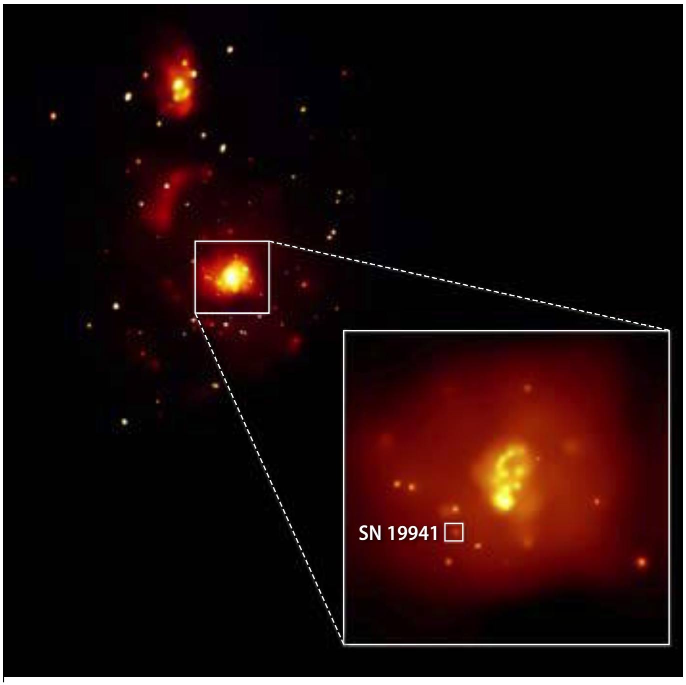
Infrared observations confirm M51 contains dust and cold gas in its spiral arms. A close look at M51's central bulge shows a highly energetic region. X-ray observations of the core indicate a high rate of star formation, also attributed to the gravitational distribution of dust and gas caused by M51's galactic encounter with NGC 5195.

NGC 5195 rides through space with the Whirlpool Galaxy. This detailed image of NGC 5195's nucleus shows fine structures of dark dust clouds silhouetted against the smaller galaxy's starlight. NASA/ESA/S. BECKWITH (STScI)/HUBBLE HERITAGE TEAM (STScI/AURA)



NRAO/AUI

THIS COMPOSITE IMAGE of the Whirlpool Galaxy combines optical and radio images along with filtered data that transmitted only light from neutral hydrogen atoms. The optical image (green and yellow) highlights young stars and dust. The radio portion (red) shows hot clouds of hydrogen. The neutral hydrogen data (blue) shows the distribution of cold gas.



ANDREW WILSON AND YUICHI TERASHIMA (UNIV. OF MARYLAND) AND STEFAN IMMLER (UNIV. OF MASSACHUSETTS)/NASA

ENERGETIC X RAYS pour from M51's heart. NASA's Chandra X-ray Observatory detected many X-ray sources due to black holes and neutron stars in binary star systems. *Inset:* This expanded image shows M51's central region. Near the bright nucleus lie clouds of multimillion-degree gas heated by high-velocity jets produced near a supermassive black hole in the galaxy's nucleus.

Moving into the realm of the weird, the Chandra X-ray Observatory discovered a new class of object in M51 and a few other galaxies. Called a quasisoft X-ray source, it may represent an intermediate-mass black hole. (Most astronomers recognize two types of black holes — stellar, with masses about 10 times that of the Sun, and supermassive, objects containing a million to a billion solar masses that lurk in the cores of galaxies.) Such quasisoft sources produce large amounts of X rays but are relatively cool. Perhaps in the violence of the collision between M51 and NGC 5195, exotic conditions developed that allowed such midsize black holes to form.

The collision between NGC 5195 and M51 also sent stars from both galaxies spiraling off into intergalactic space. These stars — and any worlds that accompany them — have become true space voyagers. The night skies of accompanying planets would be almost devoid of stars but dominated by the faint glow of nearby galaxies. Perhaps a traveler on one of these worlds will gaze back at M51 as Odysseus looked back from his "wine-dark sea" in search of a safe harbor as he navigated the maw of the whirlpool Charybdis:

"Now wailing in fear, we rowed on up those straits / Scylla to starboard, dark Charybdis off the port, / Her horrible whirlpool gulping the sea-surge down, down / But when she spewed it up-like a cauldron over a raging fire / All her churning depths would seethe and heave …" — Homer, *The Odyssey*

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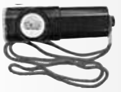

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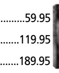

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the little comet THAT MIGHT

Uncertainty about how bright Comet 73P/Schwassmann-Wachmann 3 will be makes it a must-watch object this spring.

/// BY MICHAEL E. BAKICH

Tune up your telescope, and get ready to observe a bright comet. During May and June, Comet 73P/Schwassmann-Wachmann 3 (S-W 3) moves from the northern constellation Hercules to the southern constellation Cetus. It will flare into naked-eye visibility as it passes less than 7 million miles (11.3 million kilometers) from Earth. That alone will make it one of the brightest comets in recent times. How bright it will appear, however, remains unknown. Will it glow softly at the limit of human vision or shine as a magnitude 1 jewel? Such uncertainty is characteristic of this comet.

First observation

German astronomers Arnold Schwassmann and Arno Arthur Wachmann discovered Comet 73P/Schwassmann-Wachmann 3 on May 2, 1930. They noticed the diffuse, magnitude 9.5 object on a photographic plate taken as part of an asteroid survey. To determine the comet's orbit, they needed three positions, so they put out a call to colleagues.

Astronomers then calculated the comet's orbital period at between 5.43 and 5.46 years, near its current value of 5.36 years. This classifies it as a short-period comet. As it approached within 5.8 million miles (9.4 million km) of Earth May 31, 1930, the comet brightened to 6th magnitude.

Where did it go?

In late 1935, astronomers began looking for S-W 3. Uncertainty in its orbit, an unfavorable placement, and the comet's faintness contributed to negative results. In fact, astronomers didn't relocate S-W 3 until it showed up on a photographic plate August 13, 1979.

That year's appearance, as it turned out, was the comet's most favorable since 1930.

The object, however, was 34 days late for its closest approach to the Sun. Previous close approaches to Jupiter had changed its orbit. In 1979, the comet came closest to Earth March 19, when it lay some 133 million miles (215 million km) away and glowed feebly at magnitude 12.5.

Split personality

After calculating the comet's 1995 appearance, astronomers lost interest. Its closest approach to Earth would occur October 17. It would lie 122 million miles (198 million km) from Earth, too far away to be of interest. On August 19, S-W 3 shone at magnitude 12.9, a brightness meeting predictions.

Early in September, however, Paris Observatory astronomers using the Nancay radio telescope detected large emissions of hydroxyl molecules (OH). This meant S-W 3 was releasing huge quantities of water, which sunlight breaks apart to form OH.

◀◀ A. 73P/SCHWASSMANN-WACHMANN 3 glowed faintly during its 13th appearance since its 1930 discovery. This 120-second exposure through a 12-inch telescope November 17, 1995, shows the comet's head and a short tail. TIM PUCKETT

◀ B. EMISSIONS FROM SCHWASSMANN-WACHMANN 3 created a halo around it in this image, taken December 14, 1995. By this time, the comet's head had split into four pieces. Because the breakup revealed fresh ice the Sun could warm, the comet brightened beyond expectations. TIM PUCKETT

TONY AND DAPHINE HALLAS

The emissions increased from September 8 through the 13th. By September 17, the comet's brightness had soared a hundredfold to magnitude 8.3, where it stayed until early October, when it reached 6th magnitude — nearly 1,000 times brighter than expected. For 3 weeks, the comet faded. Then it brightened a third time to magnitude 6.3 October 22.

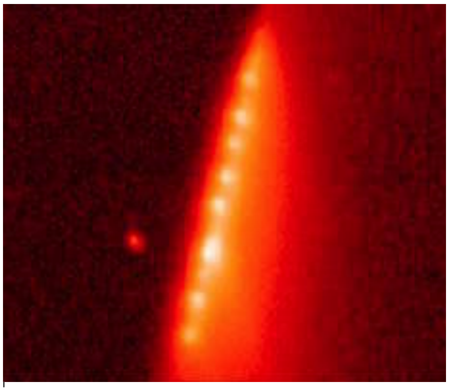
But S-W 3 had another surprise for observers. In December, observatories imaged four condensations within the comet's head. Each was a small cloud of gas and dust emanating from the nucleus' separate pieces. The comet had split.

2006 appearance

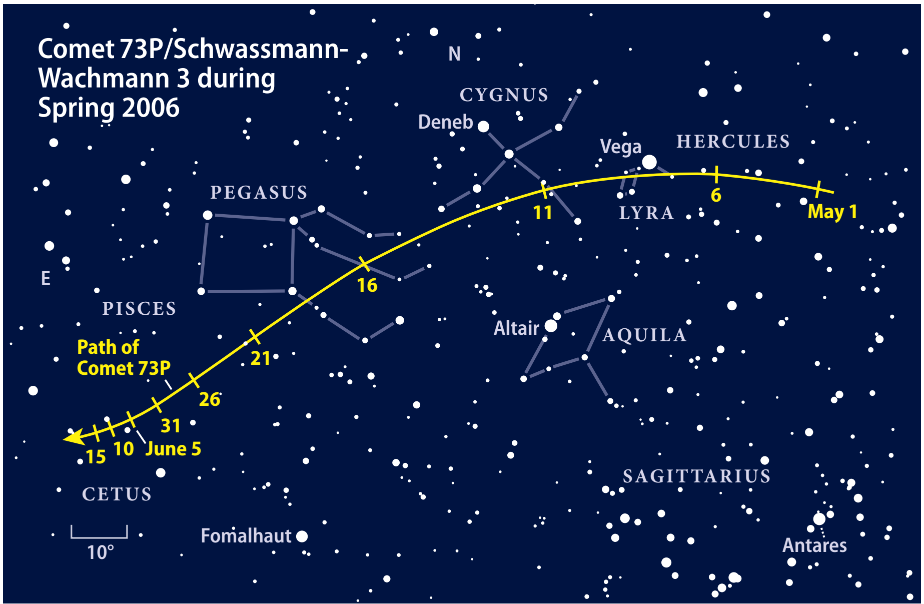
S-W 3 will lie closer to Earth this year than at any time since its discovery. At its closest, May 13, the comet sits less than 7 million miles (11.3 million km) away. Perihelion occurs June 7 at a distance of 87 million miles from the Sun.

Start watching S-W 3 no later than the beginning of May. It sits 1.75° north of magnitude 3.9 Epsilon [ε] Herculis May 1. (All positions are given at 11 P.M. EDT.) On the 7th, locate the comet only 12' east of the Ring Nebula (M57). This pairing should make a stunning telescopic sight.

On May 11, compare the comet's apparent size to NGC 6940, a magnitude 6.3 open cluster that measures about 25' in diameter. Look less than 2° southeast of the cluster. The comet reaches its closest point to Earth — and shines brightest — May 13, when it lies 10° due north of the bright globular cluster M15 in Pegasus.



COMET SHOEMAKER-LEVY 9 (S-L 9) represents another comet that broke apart. In the case of S-L 9, a close-approach to Jupiter fragmented it into 21 pieces. This image, taken March 28, 1993, shows at least 12 of them — each acted upon by the Sun's radiation, making them all individual comets. WIESLAW WISNIEWSKI/NOAO



COMET 73P/SCHWASSMANN-WACHMANN 3 rides high in the northern sky when it peaks in brightness during May and June. *ASTRONOMY*: ROEN KELLY

Unfortunately, knowing its position at mid-month may mean little because, as luck would have it, Full Moon occurs May 13. This coincidence wouldn't affect viewing if S-W 3 were a point source. But with its recent emissions, the comet may sport a faint halo larger than the Full Moon. So even if S-W 3 reaches 1st magnitude, its light will spread out over a large area of sky. Observers still should look for it near Full Moon (90° will separate the two objects), just don't set your expectations too high.

Because S-W 3 passes so close to Earth, we should get a good view of any developing tail(s). Look for the curving yellowish dust tail, which gets pushed away from the comet's nucleus by the gentle force of the Sun's radiation pressure. Also watch for the straight, bluish gas tail, which points directly away from the Sun because of the rapidly moving solar wind.

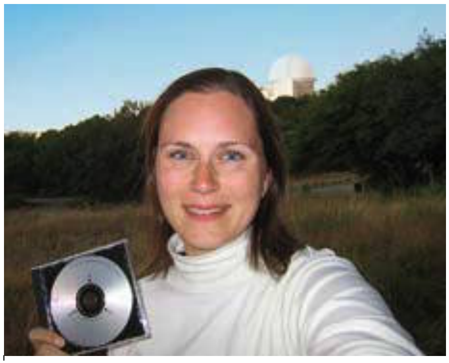
Search for S-W 3 four or more days away from Full Moon. Use binoculars or a telescope/eyepiece combination that permits at least a 2° field of view.

If the comet brightens as some astronomers expect, observers could be in for a real treat. So tune up your telescope, and study the finder chart — you won't want to miss the little comet that might.

Michael E. Bakich *is a senior editor of* Astronomy.

Kitt Peak National Observatory provides a unique fantasy camp for amateur astronomers. /// BY LAURA BAIRD

Astronomer for a night



LAURA BAIRD

AS DAWN BREAKS, **the author proudly displays a long night's reward: the raw image data saved on a compact disk.**

For a single, incredible night, I was a professional astronomer — and you can be too. Last autumn, I participated in the Advanced Observing Program (AOP) at Kitt Peak National Observatory in Arizona and spent a night using high-end equipment to image star clusters and nebulae. This program is open to the public and can be tailored to suit individual interests.

When I visited the summit on Halloween last year as a novice observer, I was especially curious about astroimaging. But I learned the AOP is just one of the public programs that makes Kitt Peak a must-go destination for the astronomy-curious.

Above the desert

Just 55 miles (88.5 kilometers) southwest of Tucson, Kitt Peak hosts the world's largest collection of optical research telescopes. The mountain juts out of the Sonoran Desert to a height of 6,875 feet (roughly 2 km). Its green vegetation and gray stone contrast the otherwise flat, ruddy landscape. Clinging to the craggy peak are 26 research telescopes, many of which the public can tour.

The biggest on the summit is the Mayall 4-meter telescope, followed by the 3.5m WIYN (Wisconsin Indiana Yale NOAO [National Optical Astronomy Observatory]), the 2.1m, and the McMath-Pierce Solar Telescope's 1.6m primary and 0.9m auxiliary mirrors. The facility also boasts several smaller scopes and radio telescopes.

An 11-mile-long (18 km) road winds its way from the base to the summit for those who make the trip. The drive to the top takes a half hour — or longer if you pull over to take in the beautiful desert vistas.

The campus is tranquil during the day, partly because signs outside the dorms remind tourists: "Quiet please, daytime sleepers." But the mountaintop comes to life when the Sun sets.

Prime time on the summit

At dusk, researchers — red flashlights in hand — make their way from the dorms to the cafeteria and then to various observatory domes. Meanwhile, people registered for the Nightly Observing Program (NOP), an introduction to astronomy, gather at the Visitor Center. Registration is required for this popular program, and the 36 nightly spots fill up quickly. I joined the group that night and observed under the darkest, clearest sky I've seen.

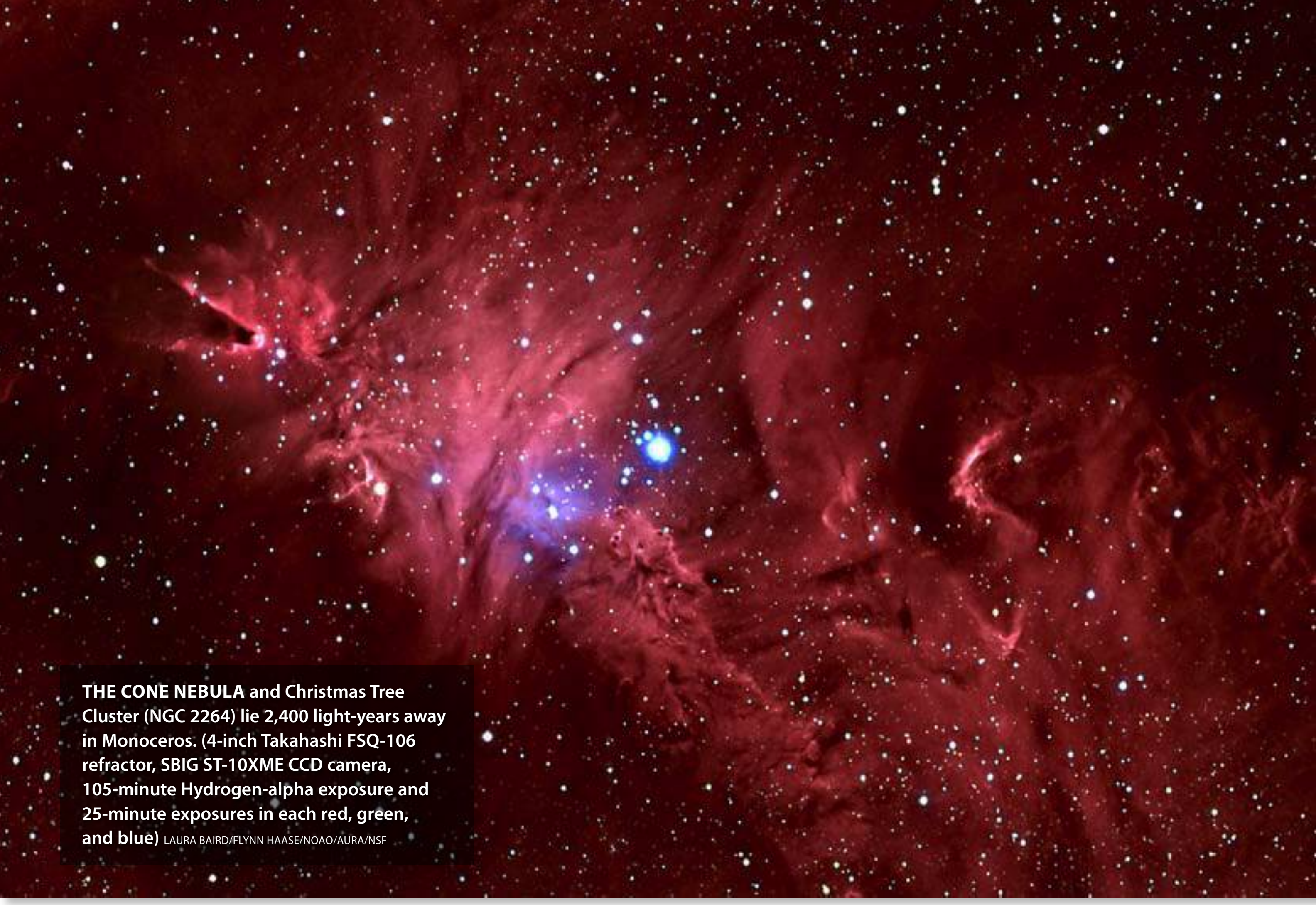
KITT PEAK IS A MUST-go destination for the astronomy-curious.

Before heading outside, our guide, Chuck Dugan, briefed us about the observatory's history and fielded astronomical questions ranging from the Hubble Space Telescope's fate to the nature of the universe's expansion. We also learned how to navigate the night sky using a planisphere and how to focus binoculars. With these two pieces of equipment strapped to our wrists and necks, respectively, we headed outside to the plaza for some naked-eye and binocular observing.

The Great Rift of dust that runs through the Milky Way was clearly visible to the naked eye, as was the Andromeda Galaxy (M31). We used binoculars to observe several objects, including the Coathanger asterism (Collinder 399), an arrangement of stars in the shape of a hanger; the Double Cluster in Perseus (NGC 884 and NGC 869), two open star clusters that appear in the same field of view; and globular star clusters M13 in Hercules and M15 in Pegasus, which each hold several thousand suns and look like fuzzy cotton balls.

We then headed to the Visitor Center's telescope dome, which holds a 20-inch RC Optical Systems Ritchey-Chrétien reflector. There, we examined the Double Double, (Epsilon [ε] Lyrae), two binary star systems in the same field of view. One of my favorite objects, the Wild Duck Cluster (M11) in Scutum, looked like diamonds strewn on black velvet. The Dumbbell Nebula (M27) in Vulpecula and the Ring Nebula (M57) in Lyra appeared as amazing balls of glowing gas. The finale was Mars, whose red glare shone unmistakably in the sky. This was prime observing time for Mars' 2005 opposition, and the planet spanned nearly 20".

Laura Baird *is the copy editor of* Astronomy.



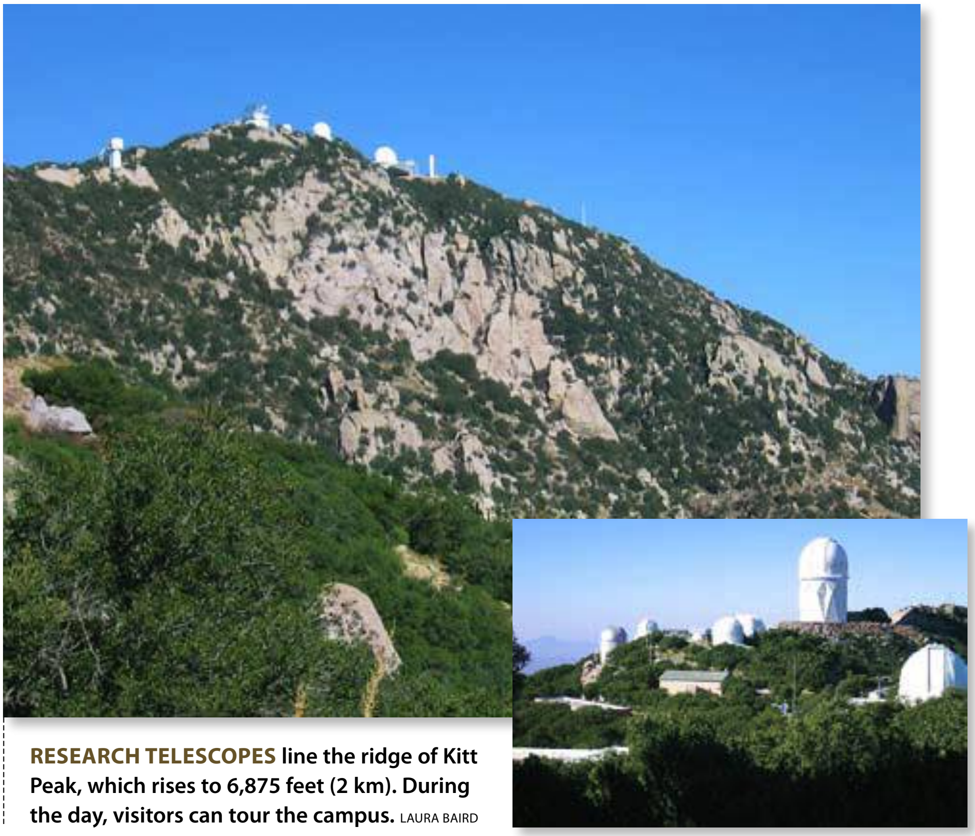
THE CONE NEBULA and Christmas Tree Cluster (NGC 2264) lie 2,400 light-years away in Monoceros. (4-inch Takahashi FSQ-106 refractor, SBIG ST-10XME CCD camera, 105-minute Hydrogen-alpha exposure and 25-minute exposures in each red, green, and blue) LAURA BAIRD/FLYNN HAASE/NOAO/AURA/NSF

After everyone had taken a turn at the eyepiece, Dugan explained he would lead a caravan down the mountainside road's first mile with no headlights! This prevents stray light from interfering with data collection on the research telescopes. I met up with Flynn Haase, my guide for the AOP, then. My night was only just beginning.

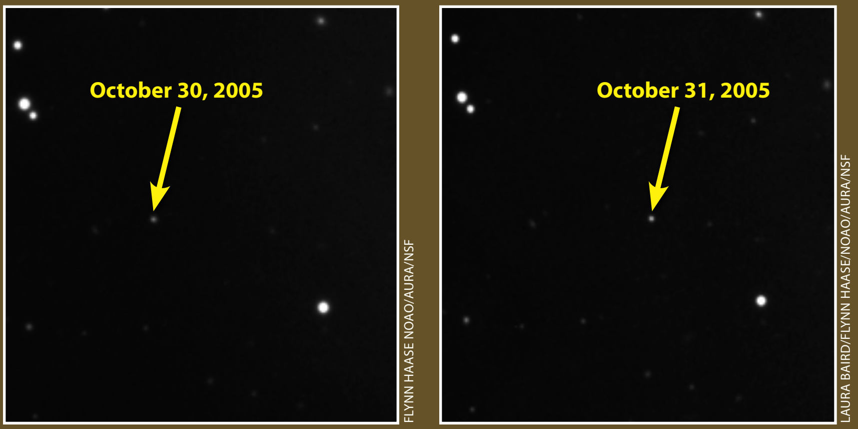
The late-night show

The Advanced Observing Program gives anyone the opportunity to explore the night sky's wonders using large amateur telescopes. "Advanced" refers to the equipment only; both novice and veteran observers can enjoy this experience. Equipment cost, access to a dark sky, and a steep learning curve might otherwise hinder people from participating in this type of activity. For a fee that includes a dorm room and meals, the telescope, equipment, and a guide are yours for a night of observing or imaging.

I wanted to try my hand at charge-coupled device (CCD) imaging, and Haase happily agreed to walk me through the process. What was evident at first blush is that



RESEARCH TELESCOPES line the ridge of Kitt Peak, which rises to 6,875 feet (2 km). During the day, visitors can tour the campus. LAURA BAIRD



FLYNN HAASE NOAO/AURA/NSF

LAURA BAIRD/FLYNN HAASE/NOAO/AURA/NSF

WHAT A DIFFERENCE A DAY MAKES

The motion of the "tenth planet," 2003 UB_{313}, is apparent in this pair of images shot 24 hours apart. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.4, SBIG ST-10XME CCD camera, 15-minute exposure for each frame)

astroimaging requires a lot of equipment. Beyond a telescope, camera, and computer are accessories like filters and software. Kitt Peak's setup includes a 20-inch RC Optical Systems Ritchey-Chrétien reflector with a piggybacked 4-inch Takahashi FSQ-106 refractor, a Santa Barbara Instruments Group (SBIG) ST-10XME CCD camera, an SBIG AO-7 unit (to stabilize images), and an SBIG CFW-8 color-filter wheel.

In this setup, a data cable feeds directly from the camera into the computer; a control cable connects the camera to the telescope and then the computer. The AO-7 unit and filter wheel attach to the front of the camera, which is then fixed to the telescope's eyepiece holder with setscrews.

Once Haase and I had wired the hardware, we used Software Bisque's *TheSky6* to comb the virtual sky in search of targets. This version of the software features pop-up thumbnail images of deep-sky objects. That way, we could preview our quarry before committing to imaging it. Our game plan: the Pleiades (M45) in Taurus; and, later in the evening when they were overhead, the Cone Nebula and Christmas Tree Cluster (NGC 2264) in Monoceros.

But first up was the object 2003 UB_{313}, also called Xena and known famously as the tenth planet. Haase had imaged the newly discovered world the previous night and was curious to see if we could track its motion by comparing two shots. I studiously watched him calibrate the equipment and program the computer — my turn would come later.

The process was the same for each image. We used *TheSky6* to point the telescope at the target. Focusing was next for both the telescope and camera. The 20-inch has a motorized focuser, so we used *FocusMax* software to adjust the telescope in tandem with *MaxImDL* software, which controls the camera. The refractor has a manual focus; so when we imaged M45 and NGC 2264, we adjusted the scope by feel (no eyepieces here), continually checking the computer-screen readouts.

Next, we located a guide star in the camera's field of view (projected onto the computer screen) that the system could track. The telescopes ride on a motorized equatorial mount that keeps the target centered while Earth rotates, but astroimaging demands even more precise tracking so images aren't blurred. Calibrating the system required taking two snapshots; software measures the horizontal and vertical distances the guide star moves between frames and then compensates for that movement during exposures.

The final step before shooting was to frame our object. For Xena, we tried to match the previous night's image so we could compare the planet's movement against the background stars. For the Pleiades and Christmas Tree Cluster, choosing a frame was more subjective.

At this point, we turned off or shielded all nearby lights, including the camera's green power indicator, the computer screen, and the observatory's red walkway lights. We carefully made our way down the stairs to the Visitor Center and retreated inside to the control room. As the night wore on, the temperature fell to around 40° Fahrenheit (4° Celsius) with a bone-chilling wind. Needless to say, the control room was where we spent most of our time.

At the controls

In a small office crammed with two desks, three computers, a small refrigerator, and bookshelves lining the walls to the ceiling, we programmed a series of exposures. For Xena, we took a 15-minute frame. For M45, we took four 3-minute exposures through three filters: red, green, and blue. For NGC 2264, we took five 5-minute exposures in each color and seven 15-minute Hydrogen-alpha (Hα) exposures.

Occasionally, a completed exposure would flash on the computer screen, and then the next one would begin. After we collected data for each object, we shot a "flat field," which records how evenly light hits the camera pixels. For this, we imaged the observatory wall evenly illuminated by a mini-spotlight. Then, we shot a "dark frame" with the camera shutter closed. This revealed any "hot pixels" in the camera that would show up as spots in the image. Haase later removed these spots from the pictures.

For the star-cluster images, I attached the camera to the Takahashi refractor, focused and calibrated the system, and framed the shots. Several times throughout the night, Haase ran outside to move the observatory dome. During downtime, we drank coffee and ate candy to stay awake.

As dawn broke, the last Hα exposure of NGC 2264 ended. We finished the night

JACK KENNEDY/NOAO/AURA/NSF

AOP GUIDE FLYNN HAASE shows off the imaging setup at Kitt Peak: a 20-inch RC Optical Systems Ritchey-Chrétien reflector with a piggybacked 4-inch Takahashi FSQ-106 refractor, an SBIG ST-10XME CCD camera, SBIG AO-7 adaptive optics unit, and SBIG CFW-8 color-filter wheel.

THE PLEIADES (M45), a naked-eye sight, shines some 440 light-years away. (4-inch Takahashi FSQ-106 telescope, SBIG ST-10XME CCD camera, RGB image with 12-minute exposures in each color) LAURA BAIRD/FLYNN HAASE/NOAO/AURA/NSF

with a "bias frame," which records any electronic noise generated when the computer reads the CCD chip's data; this was also subtracted out during image-processing. Haase then burned the raw data files onto a compact disk for me to take home.

A one-of-a-kind experience

Although I had been up all night, I watched the Sun rise before heading to my dorm. Our star shed a pink glow over the desert and washed out the remaining stars overhead. Like a celestial alarm clock, this signaled an end to my time as an astroimager. But what Haase and I did Halloween night was only half the work needed to produce a great celestial portrait. In the weeks that followed, he did all the image-processing.

Three images were the product of my visit to Kitt Peak, but my experience there was more than this. The Nightly Observing Program provided a hands-on introduction to the night sky, while the Advanced Observing Program was an intense all-nighter. Anyone curious about the universe should visit Kitt Peak and become an astronomer for a night. It's an amateur astronomer's fantasy camp.

SIGN UP TODAY!

Both the Nightly Observing Program (NOP) and Advanced Observing Program (AOP) at Kitt Peak require reservations.

The NOP costs $39 ($34 for seniors and students) and includes a sack lunch. The AOP fee is $375 per night for up to 2 people and $50 for each additional person. Room and board is $75 per night for one person or $60 per person for double occupancy; this fee covers meals, including a middle-of-the-night "dinner."

Kitt Peak National Observatory is open daily except during monsoon season, July 15–August 31. One-hour guided tours begin at 10 A.M., 11:30 A.M., and 1:30 P.M., and group tours are available by appointment. Admission to the observatory is free, but donations are welcome. Tours cost $2.

For more information or to sign up, call the Visitor Center at 520.318.8726 or visit www.noao.edu/outreach/kpvc. Spots fill up quickly for these popular programs. — *L. B.*

THE VISITOR CENTER is the departing point for daytime tours. At night, it hosts the Nightly Observing Program and Advanced Observing Progam. LAURA BAIRD

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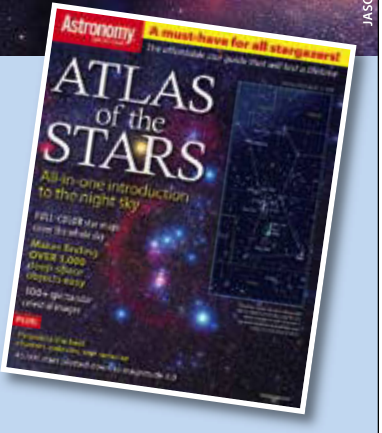
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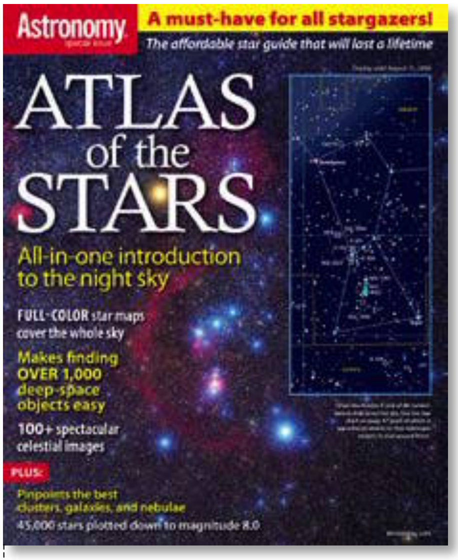

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Atlas of the Stars divides the sky into 24 manageable sections. Each part is a two-page, full-color star chart. Together, the charts cover the entire sky, displaying all 88 constellations. With a brightness limit of magnitude 8.0, we found we could show more than 45,000 stars, while still keeping the charts easy to navigate.

Amateur astronomers who spend time at their telescopes find deep-sky objects (star clusters, nebulae, and galaxies) the best targets to observe, and you'll find more than 1,000 in the atlas. We were careful to provide overlap for the charts, so you won't lose any objects at the edges. Each chart has a two-page introduction that points observers to the best objects. We also include 24 lists of the finest double stars — one for each chart. And that's not all.

In addition to the star charts, *Atlas of the Stars* contains lots of observing-related information. Some is in the form of lists: the Messier objects, the Caldwell objects, the constellations, the brightest star clusters, and the reddest stars. (Each list includes which chart the object is on.) Articles target the needs of beginning amateur astronomers with topics ranging from the magnitude system and how to measure angular distance in the sky to getting the most out of a star party.

Another attribute of *Atlas of the Stars* is its usable lifetime. We included lots of stars and deep-sky objects but no solar system targets for one reason: motion. The Sun, Moon, planets, comets, and asteroids move against the background stars, so their positions continually change (and we detail their positions in each issue of *Astronomy*). So, although star and deep-sky object positions in *Atlas of the Stars* won't be accurate forever, it's safe to say it won't go out of date during your lifetime.

The star-map introductions also contain dozens of full-color images that showcase the best objects. Finally, we selected more than 1,000 deep-sky objects — telescopic targets that will fascinate you for years.

Yes, we've packed *Atlas of the Stars* full of great stuff, but we didn't forget value: All this is yours for only $12.95. You won't find a better deal in all of the universe. Look for it on newsstands beginning May 15, or order it now from Astronomy.com.

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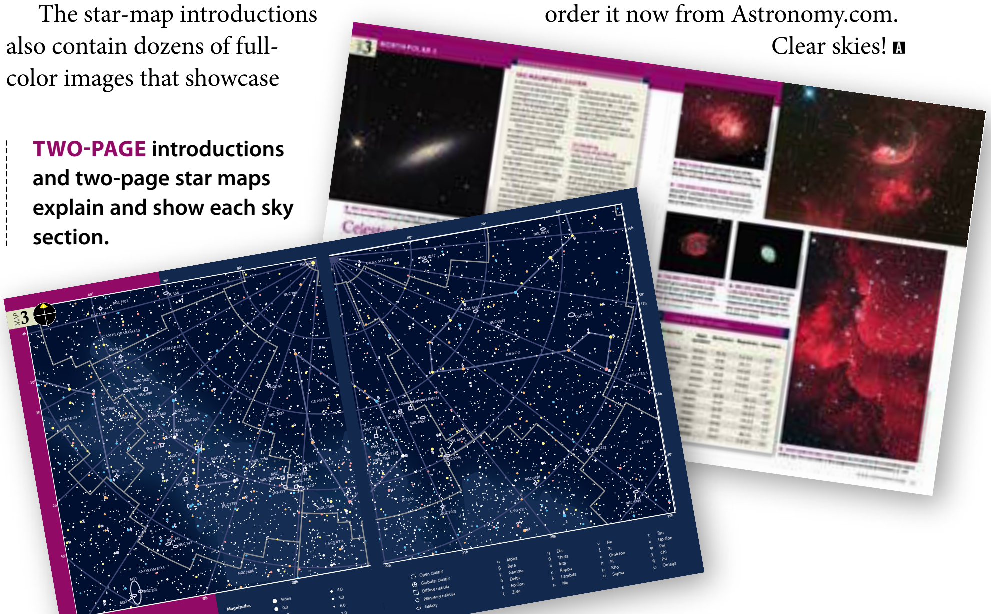

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Michael E. Bakich *is a senior editor of* Astronomy.

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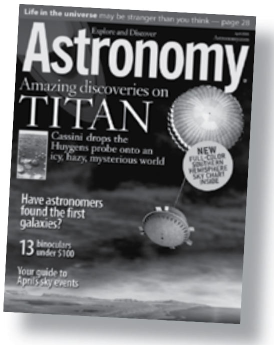

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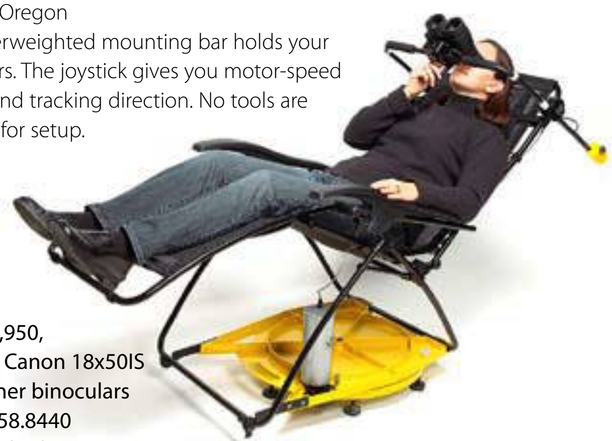

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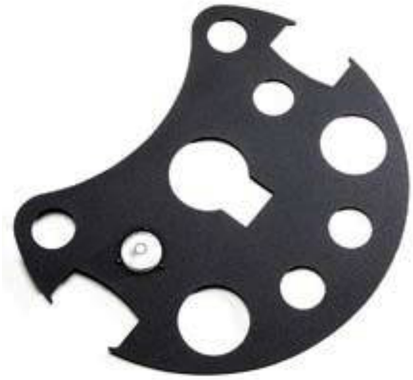

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Each year, amateur astronomers descend on Dayton, Ohio, the birthplace of aviation, for the Apollo Rendezvous. Hosted at the Boonshoft Museum, this annual gathering has been one of the premier astronomy conventions and star parties for more than 35 years.

JOHN CHUMACK

THIS MILKY WAY VIEW was captured during last year's Apollo Rendezvous. This year's event will feature 2 nights of observing. Attendees may bring their own instruments or peer through several MVAS scopes. Astroimagers are encouraged to shoot the sky.

The Miami Valley Astronomical Society (MVAS) and *Astronomy* magazine will sponsor this year's gathering.

During the day, attendees will find exhibits, workshops, raffles, and vendors. The Apollo Rendezvous will present numerous lectures, including one by *Astronomy* Editor David J. Eicher.

As the Sun begins to set June 17, participants will relocate to the John Bryan State Park Observatory — an abandoned Air Force satellite tracking station and the MVAS's dark-sky site. After a barbecue, the event will close with telescope tours of the night sky.

For more information, contact Kevin Frederick at 937.236.4090; e-mail, kcrlfred@sbcglobal.net or mvas@mvas.org; web site, www.mvas.org.

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MAY 5–6

Northeast Astronomy Forum and Telescope Show

Rockland Community College, Suffern, New York. This annual gathering features lectures by prominent astronomers. *Astronomy* Editor David J. Eicher will attend. For more information, visit www.rocklandastronomy.com.

MAY 6

Astronomy Day in Clute

Brazosport Planetarium, Clute, Texas. Sponsored by the Brazosport Astronomy Club, this rain-or-shine event will include stargazing, planetarium shows, and hands-on activities. The planetarium houses a Spitz Star Ball — the projector NASA uses to train astronauts in star identification. For more information, visit www.bcfas.org.

MAY 14–16

Meeting on Asteroids and Comets in Europe

Kuffner Observatory, Vienna, Austria. Scientists will convene at this meeting to discuss minor bodies traveling through the solar system. Related topics include advances in telescope design, observing methods, and remote observation systems. For more information, visit www.minorplanets.org.

MAY 18–22

Royal Astronomical Society of Canada General Assembly

Ottawa, Ontario. This event will feature lectures, displays, and tours, including the Canada Museum of Science and Technology. For more information, visit www.rasc.ca/ga2006.

MAY 20

Fun ‘n’ Sun

Lodestar Astronomy Center, Albuquerque, New Mexico. Part of the Lodestar’s Family Astronomy program, this event will educate the entire family about the Sun. The center hosts a monthly family-oriented day focusing on a different astronomy topic. For more information, visit www.lodestar.unm.edu.

MAY 24–28

International Telescope Meeting Vogelsberg

Feldatal-Stumpertenrod, Germany. This event will feature lectures, observing, and telescope-making. For more information, visit www.teleskoptreffen.de/itv.

MAY 25–29

Wisconsin Observers Weekend

Hartman Creek State Park, Waupaca, Wisconsin. Hosted by the Northeast Wisconsin Stargazers, this event’s campsites are reserved, limiting light-pollution from other campers. For more information, contact Tom Riederer at 920.734.0248; web site, www.new-star.org/wow.

MAY 26–28

Riverside Telescope Makers Conference (RTMC)

YMCA Camp Oakes, near Big Bear City, California. The RTMC is one of the most popular astronomy gatherings in the Golden State. This year’s theme is “Preserving and Enjoying the Night Sky.” Featuring clear, high-altitude observing, workshops, and lectures, this event draws stargazers from around the world. *Astronomy* Associate Editor Laura Layton will attend. For more information, e-mail registrar@rtmcastronomyexpo.org; web site, www.rtmcastronomyexpo.org.

MAY 27

Texas Guitars and Stars Fest

Lake Whitney State Park, Whitney, Texas. This gathering combines music and astronomy. Guitarists will entertain during the day, and observing takes center stage at night. For more information, contact Thomas Williamson at 817.656.0901; e-mail, distglow@sbcglobal.net; web site texas-stars-guitars.com.

CONTACT INFORMATION

Please submit club announcements 5 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

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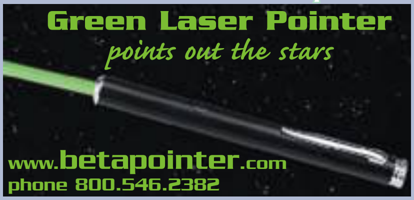
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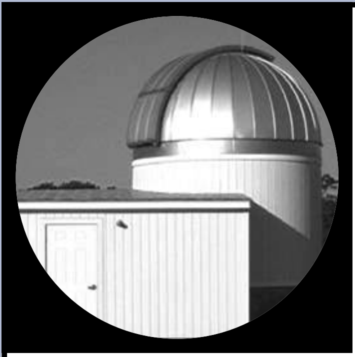

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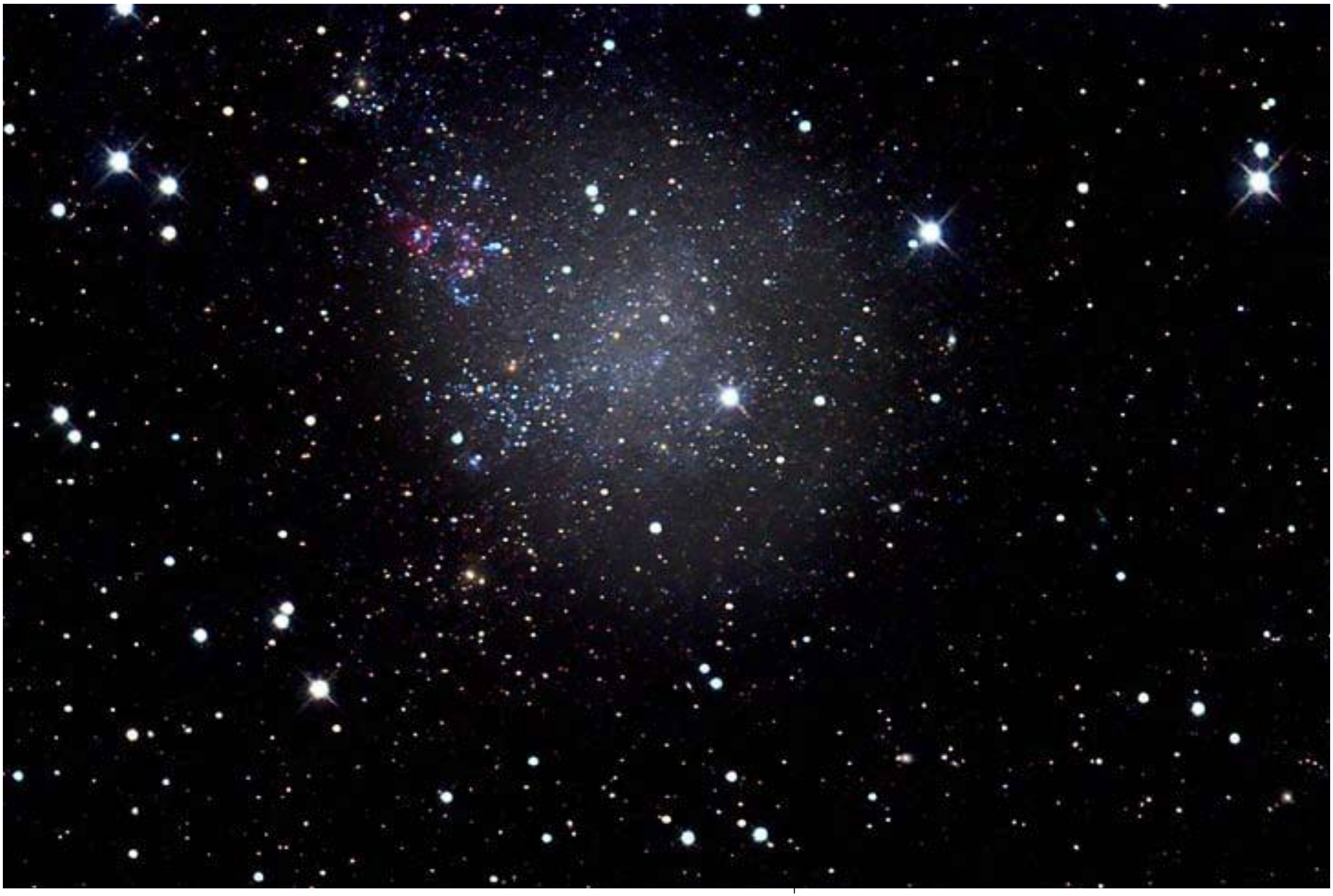


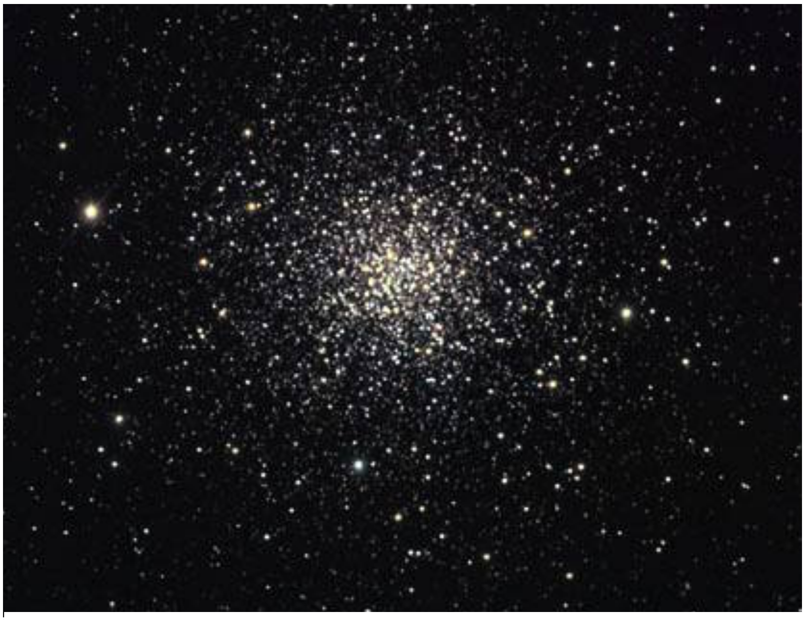
▲ **IRREGULAR DWARF GALAXY IC 1613** (12.5-inch homemade Newtonian reflector at f/5, SBIG ST-10XME CCD camera, LRGB image with exposures of 120, 20, 20, and 20 minutes, respectively) /// **CHRIS SCHUR, PAYSON, ARIZONA**

FAINT-OBJECT IMAGING

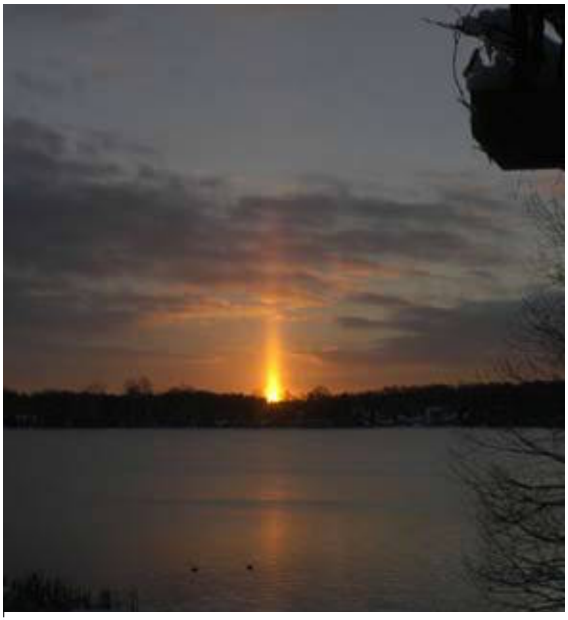
A galactic neighbor

Astronomers classify IC 1613 in Cetus as an irregular dwarf galaxy. It belongs to the Local Group, a collection of some 40 galaxies that contains the Milky Way and the Andromeda Galaxy (M31). IC 1613 measures 16' by 15', so it appears fainter than its magnitude of 9.2 suggests. IC 1613 lies 2.4 million light-years away, and two galaxies lie within its borders. MAC0105+0204 and MAC014+0207 each glow faintly at 17th magnitude. Both lie much farther away than IC 1613, so they are unrelated to it. Asteroid 1998 FV67 made a visit to this area during this image's exposures. The red, green, and blue dots represent the asteroid captured through RGB filters.

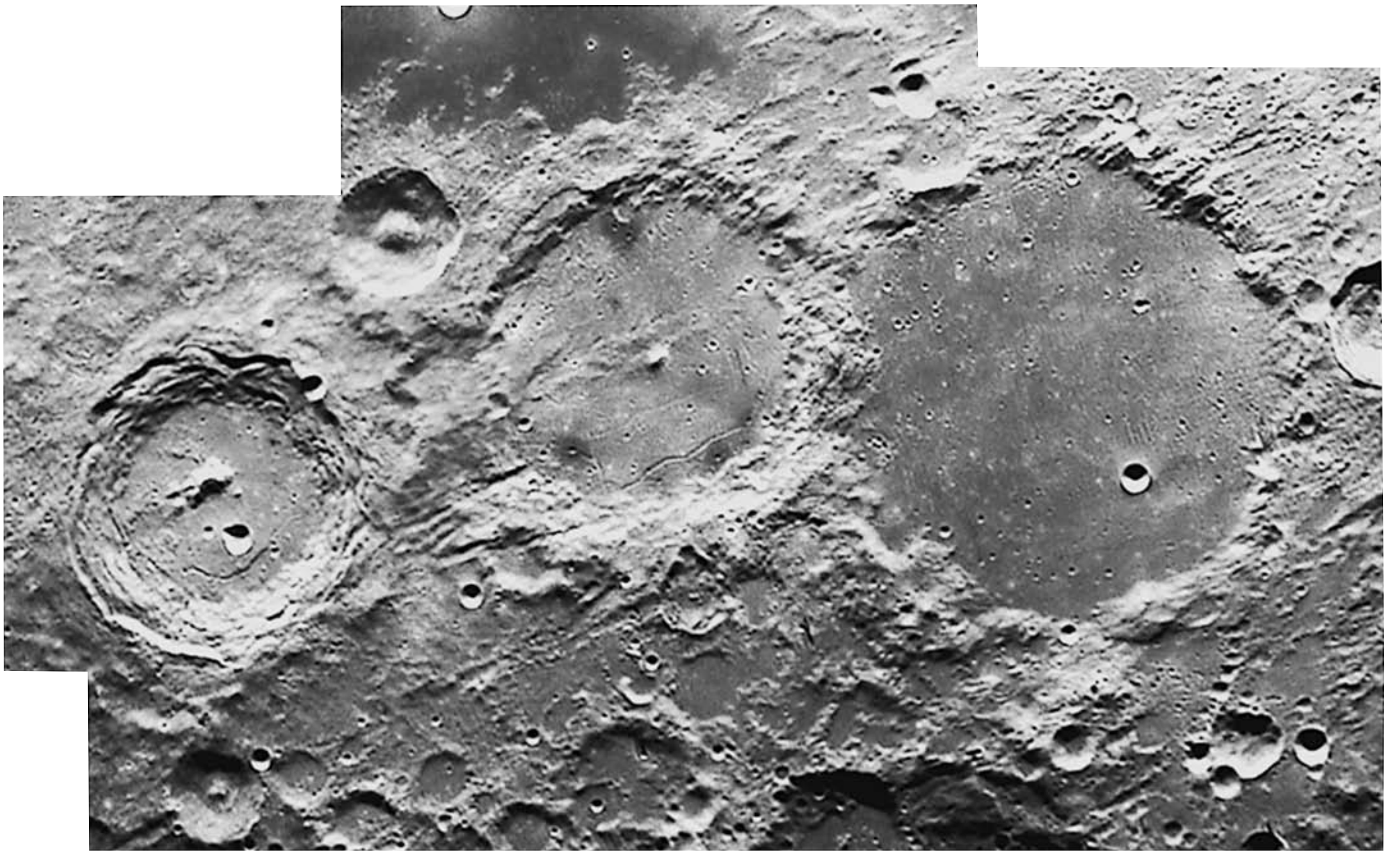
▶ **LUNAR CRATERS** Arzachel, Alphonsus, and Ptolemaeus (large craters from left to right) mark an area near the center of the Moon's nearside. (10-inch Orion-optiks Newtonian reflector at f/4.8, Philips ToUcam PCVC740k webcam, 3-part mosaic, six images each, 1⁄25-second exposures, taken September 5, 2004) /// **RALF VANDEBERGH, WITTEM, NETHERLANDS**

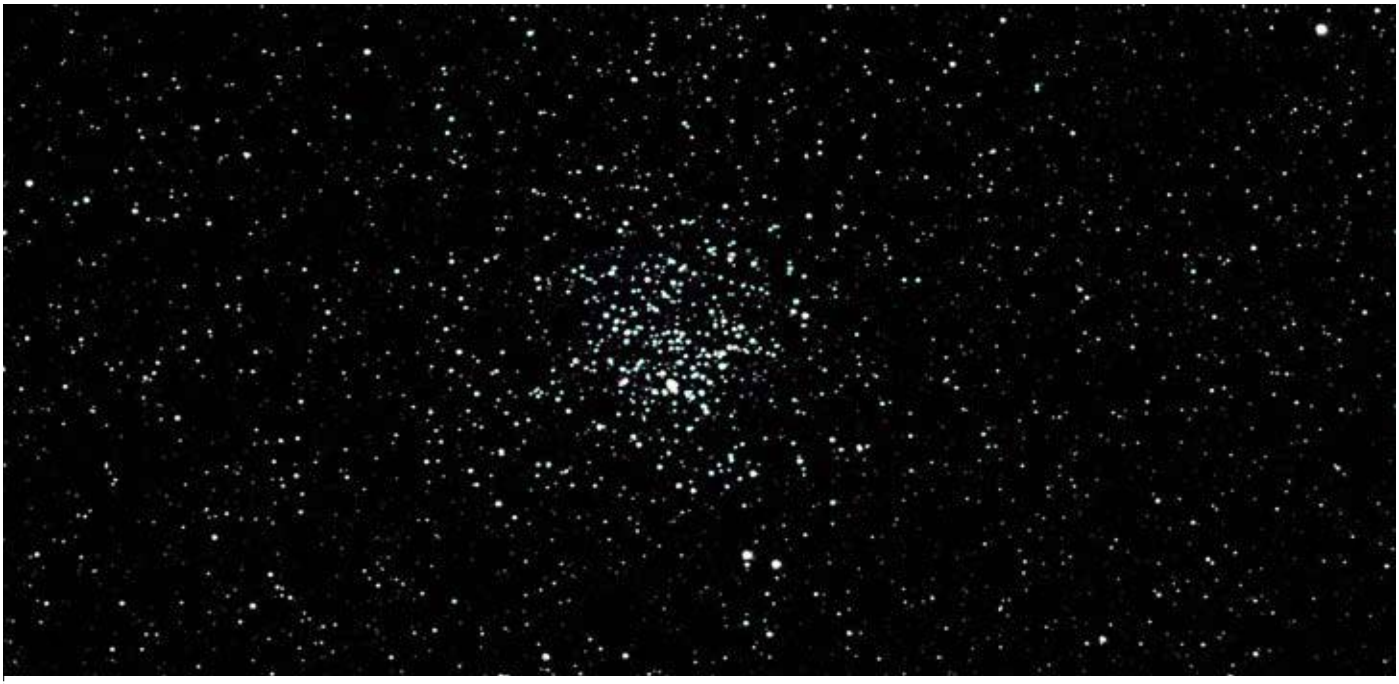


GLOBULAR CLUSTER M107 in Ophiuchus shines at 8th magnitude. It lies roughly 21,000 light-years away and races toward us at 325,000 mph (525,000 kilometers/hour). (20-inch RC Optical Systems Ritchey-Chrétien reflector at f/8.4, SBIG ST-10XME CCD camera, LRGB image with exposures of 15, 5, 5, and 5 minutes, respectively) /// **BRUCE HUGO AND LESLIE GAUL/ADAM BLOCK/NOAO/NSF, KITT PEAK NATIONAL OBSERVATORY, ARIZONA**

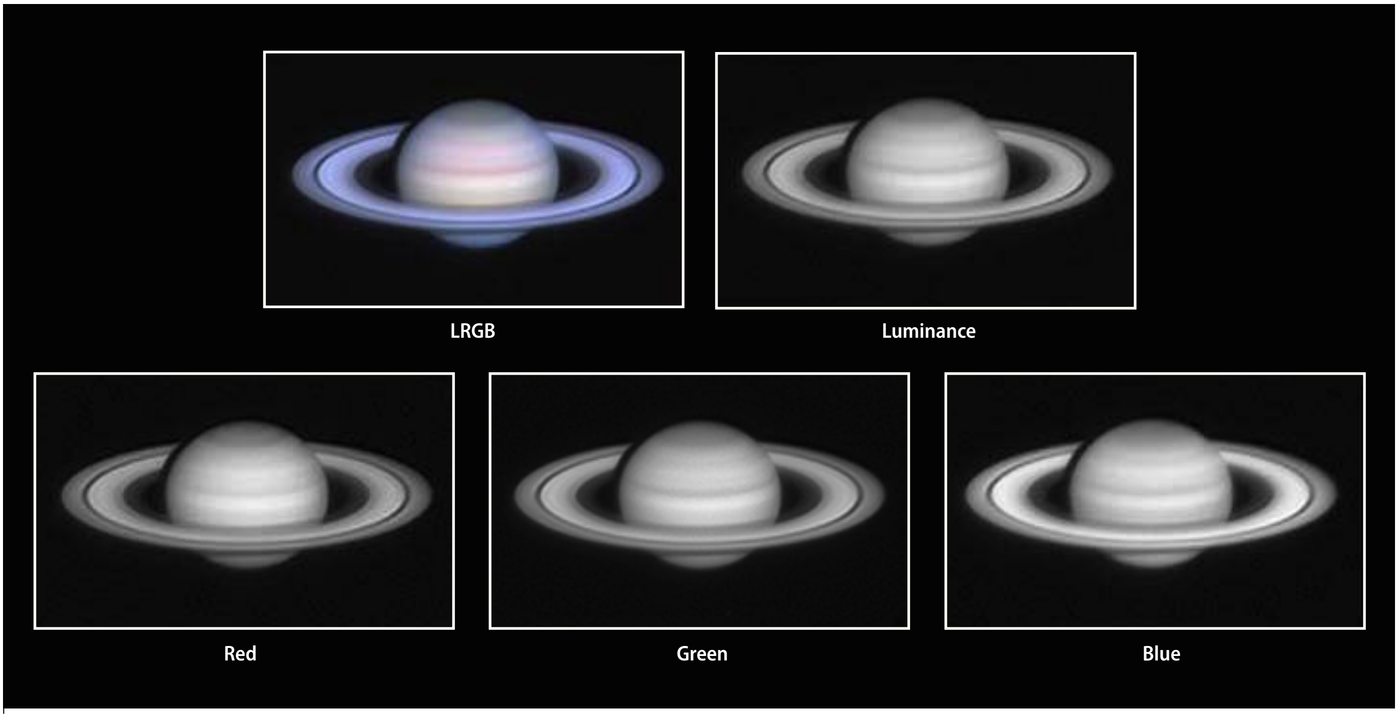


A SUN PILLAR forms when the Sun lies just below the horizon and illuminates hexagonal ice crystals in high, thin cirrus clouds. (Nikon D100 digital SLR, Nikon 24mm lens at f/2.8, taken before sunrise November 25, 2005, at Twin Lakes, Kent, Ohio) /// **ERNIE MASTROIANNI, WHITEFISH BAY, WISCONSIN**



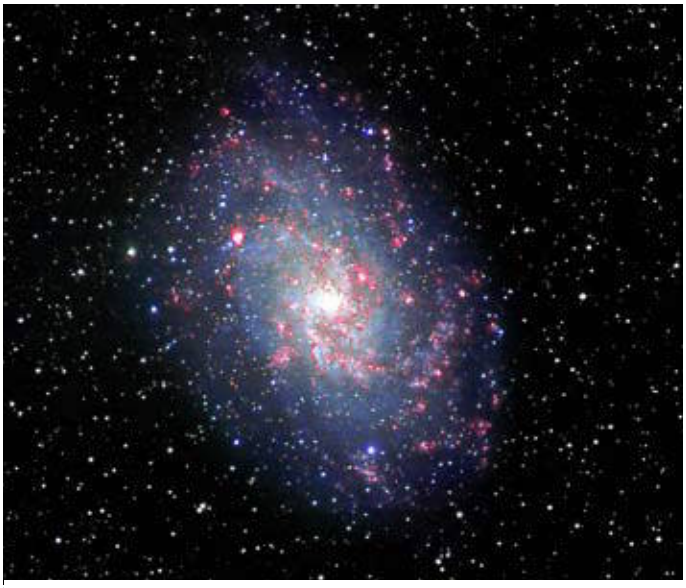


THE WILD DUCK CLUSTER (M11) lies in Scutum. This open cluster shines at magnitude 6.3. Sharp-eyed observers can spot M11 with their unaided eyes from a dark site. (8-inch Intes Micro Maksutov-Newtonian at f/6, SBIG ST-2000XM CCD camera, RGB image combining twenty 2-minute red, fifteen 2-minute green, and fifteen 2-minute blue exposures) /// **DEAN SALMAN, TUCSON, ARIZONA**

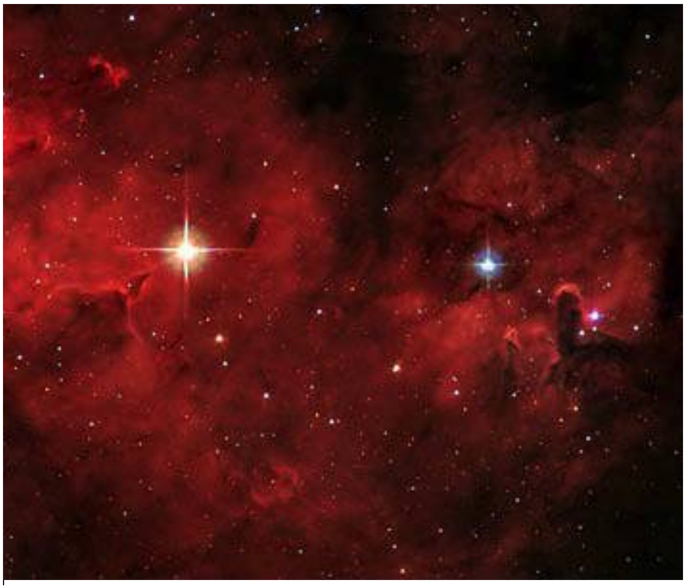


SATURN displays many fine details in this image: The dark Cassini Division divides the outer A and B rings; the inner Crepe ring (also called the C ring), which is elusive to visual observers, stands out well; and the dark south polar cap crowns the top of the image. (12.4-inch Spada Dall-Kirkham reflector at f/25, Lumenera Infinity 2-1M CCD camera, LRGB image with the best 800 of 2,500 0.05-second images selected for each color, taken October 27, 2005, at 4h17m UT) /// **PAOLO LAZZAROTTI, MT. GIOGO, MASSA, ITALY**

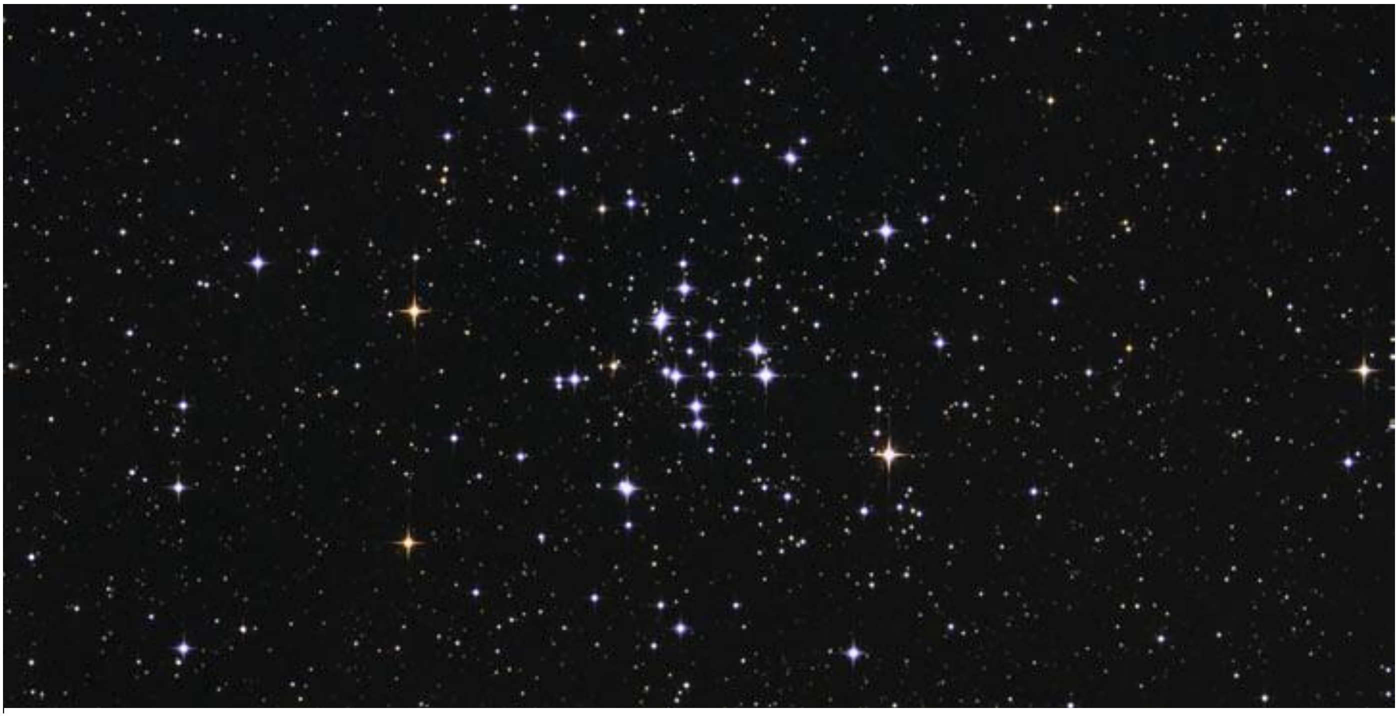
Send your photos to: *ASTRONOMY* Reader gallery, P. O. Box 1612, Waukesha, WI 53187; e-mail to readergallery@astronomy.com. Please include your full name, date and location of image, and complete photo data: telescope, camera, film, and exposure information.



THE PINWHEEL GALAXY (M33) in Triangulum ranks as the third-largest member of the Local Group. Only the Andromeda Galaxy (M31) and the Milky Way surpass it in size. (800mm Nikon Super-Telephoto lens at f/5.6, SBIG STL-6303E CCD camera, HαLRGB image with exposures of 120, 144, 32, 32, and 32 minutes, respectively.) /// **PAOLO CANDY, SORIANO NEL CIMINO, ITALY**

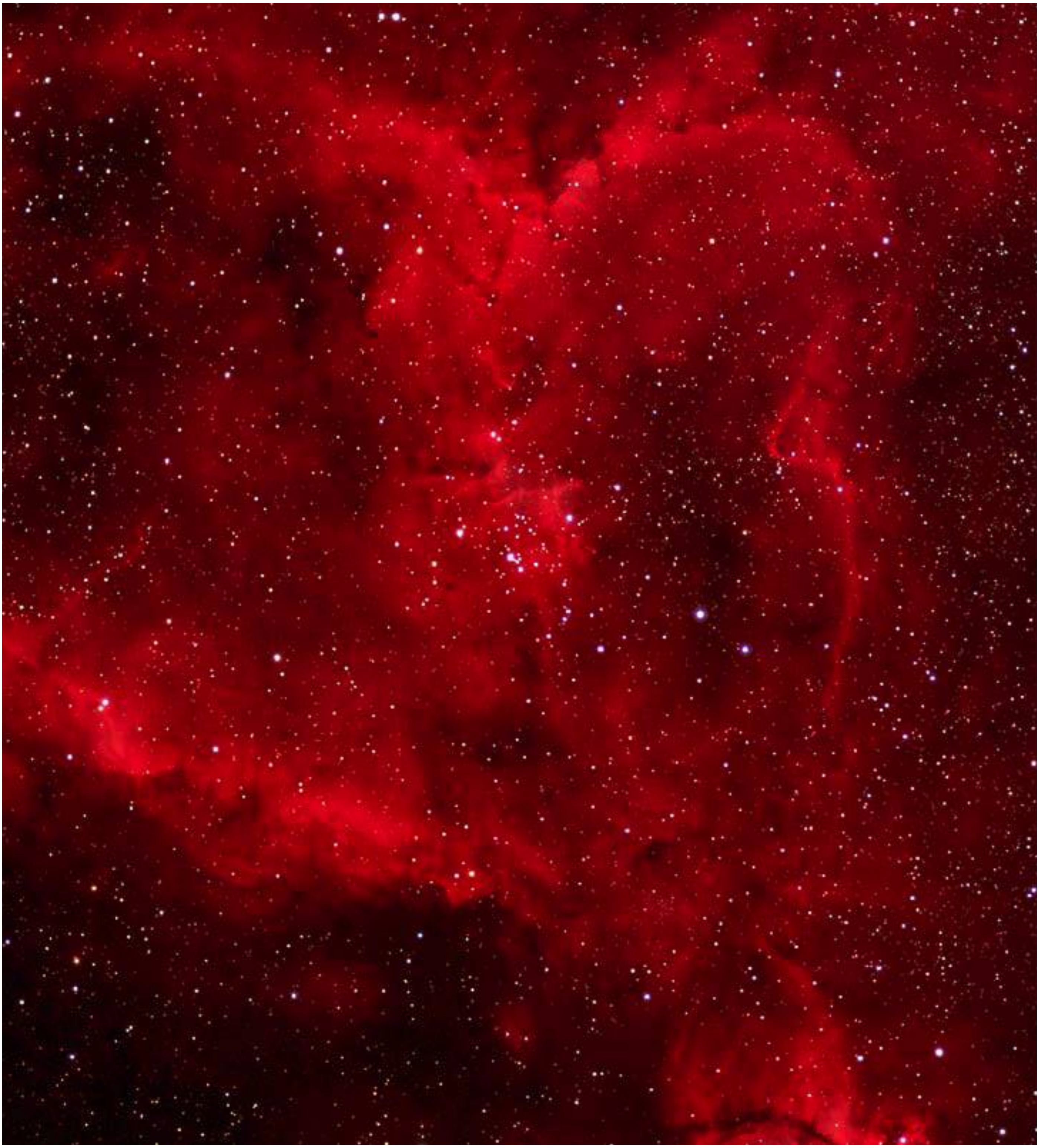


EMISSION NEBULA CEDERBLAD 214 in Cepheus shines in the red hues of Hydrogen-alpha light. Astronomers classify Cederblad 214 as an active star-forming region. (6-inch Celestron C6N Newtonian reflector at f/5, Starlight Xpress SXV-H9 camera, HαRGB image with exposures of 120, 15, 15, and 15 minutes, respectively) /// **WOLFGANG PROMPER, GAENSERNDORF, AUSTRIA**



OPEN CLUSTER M34 in Perseus measures 35' across — slightly larger than the Full Moon. M34 lies 1,400 light-years away and shines at magnitude 5.5. Find this cluster 5° west-northwest of Algol (Beta [β] Persei). Through an 8-inch scope, you'll see about 100 stars. (3.6-inch Takahashi SKY 90 apochromatic refractor at f/4.5, Starlight Xpress SXV-H9 CCD camera, LRGB image that combined eight 2-minute L plus five 3-minute R, G, and B exposures) /// **STEVE CANNISTRA, NEEDHAM, MASSACHUSETTS**

THE HEART NEBULA (IC 1805) in Cassiopeia combines glowing gas clouds, dark dust clouds, and the star cluster Melotte 15 at the nebula's center. American astronomer Edward Emerson Barnard first observed IC 1805 through a 6-inch refractor. (3.6-inch Takahashi SKY 90 apochromatic refractor at f/5.6, Starlight Xpress SXV-H9 CCD camera, Astrodon filters, HαRGB 4-part mosaic; each part consists of between seven and ten 510-second Hα exposures, four 520-second red, four 400-second green, and four 400-second blue exposures) /// **PIERRE TREMBLAY, QUEBEC CITY**



Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Publishing Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Canada Publication Mail Agreement # 40010760.

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